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TEXTILE RESEARCH JOURNAL

VOL. XVIII, No. 12 December, 1948

# Mechanics of Elastic Performance of Textile Materials*

## II. The Application of Sonic Techniques to the Investigation of the Effect of Visco-Elastic Behavior upon Stress-Strain Relationships in Certain High Polymers†

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### Abstract

A technique is developed for the quantitative evaluation of the deformation components of visco-elastic materials when these are subjected to tensile loading, for loads ranging from zero to rupture, under dynamic loading conditions, at constant rates of load, elongation, or strain for different magnitudes of constant rates of load, elongation, and strain. The technique serves not only to determine the mechanism of elastic performance of materials but also to quantitatively evaluate their performance characteristics as engineering materials.

A sensitive and responsive instrument for the determination of the dynamic modulus of elasticity of materials under any and all loading conditions, such as those enumerated above, has been developed and is described.

The effects of the visco-elastic behavior of high polymers upon their stress-strain relationships are investigated and discussed.

### Introduction

The rapid development of the man-made fibers and their impact upon the textile industry has accented the necessity of defining, in quantitative terms, the performance characteristics of fibrous and non-fibrous visco-elastic materials, as well as the characteristics of the ultimate structures fabricated from them. The work of Peirce and coworkers [11], Leaderman [8], Eyring and coworkers [4], Smith [12], and others has stimulated a philosophy of approach to the field of textile physics which is based upon the concept that the evaluation of the performance of such materials is governed by the

* Part I of this series appeared in the February, 1948, issue, page 102.

† Dissertation submitted to the Graduate Faculty of the Polytechnic Institute of Brooklyn in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Portions of this paper were presented at the Fiber Society, spring, 1948, meeting, and at the Gordon Research Conferences, July, 1948.

same physical and engineering principles which have been used so successfully in the evaluation of the more classical structural materials, such as wood, steel, concrete, etc.; but that the basic deterrent in the application of these principles to visco-elastic materials in the past is attributable to the fact that they deviate in their elastic performance from that of the structural materials as a result of the manifestation of delayed elastic and plastic after-effects [8].

The late Harold DeWitt Smith, in his foreword to Leaderman's *Elastic and Creep Properties of Filamentous Materials and Other High Polymers*, states:

"Time is a dimension to be reckoned with in any study of the physical properties of matter, especially the kinds of matter of which good textile fibers and plastics are composed. The ease with which we can observe the immediate changes which occur in an apparently solid substance as a result of the application of a force often conceals the fact that the total change does not necessarily occur instantly, but may continue, in some measure, as long as the force continues or until a new equilibrium is established.

"Since the beginning of the rapid commercial development of the man-made fibers . . . both the natural fibers and the man-made fibers have been subjected to a scientific scrutiny which revealed, among other things, that the creep and creep recovery of the substances of which the most useful textile fibers are composed form a far greater part of the total behavior under stress than is the case with the more rigid materials of construction, such as metals and glass. . . .

"The man-made fiber industries which are concerned with the production of 'tailor-made' fibers, as well as the older textile industries which are concerned with the artistic and profitable utilization of textile fibers of all kinds and origins, must depend more and more on the knowledge of the stress-strain-time-temperature-humidity behavior which physicists . . . can provide, and must have on their staffs men who can understand and apply this knowledge to the problem of fiber manufacture and fabric design."

## Purpose of Investigation

The purpose of this investigation is threefold:

1. To develop a technique for the quantitative evaluation of the deformation components of visco-elastic materials:

(*a*) For loads ranging from zero to the load at which rupture occurs.

(*b*) Under dynamic loading conditions.

(*c*) For constant rates of load, elongation, and strain.

(*d*) For different magnitudes of constant rates of load, elongation, and strain.

2. To develop sensitive and responsive instruments for the measurement of these deformation components under any and all of the conditions enumerated in (1).

3. To determine the effects of the visco-elastic behavior of high polymers upon their stress-strain relationships.

This study has been undertaken not only for the purpose of determining the mechanism of the elastic performance of materials, but also for the purpose of quantitatively evaluating their performance characteristics as engineering materials.

In contrast to the fundamental studies conducted for relatively light loads, with non-recoverable deformations absent, this work undertakes to evaluate the visco-elastic behavior of high polymers under conditions in which all deformation components are interacting simultaneously under complex dynamic loading conditions. As a consequence, the results should be not only of scientific interest, but also of great practical value in the study of such material characteristics as abrasion-resistance, elastic performance, resilience, crush-resistance, dimensional stability, etc.

## History and Literature

Weber carried out the classic experiment on creep in Göttengen in 1835 [14], during which he observed, while investigating the mechanical properties of a silk filament, that the application of an axial load was accompanied by an immediate elastic extension which gradually increased with time. Upon removal of the load, there took place an immediate elastic contraction of the specimen equal to the initial immediate extension. He further observed that if the specimen were allowed to remain free from load and undisturbed, a gradual contraction took place, which, under certain circumstances, resulted in the specimen eventually regaining its original length. Weber commented as follows:

"The well-known laws of elasticity are concerned mainly with the ratio between strain and stress in equilibrium. This ratio is assumed to be always constant in one and the same filament; the law states that the ratio of strain to stress is the same whether the stress is large or small, or whether it is maintained for a long or a short time. . . . However, the observations reveal that, with a maintained loading, there is an extension calculable with the law of proportionality from the

modulus of elasticity, and, in addition, a further extension which takes place over a long period of time. This further extension is not defined in the law of elasticity, and is to be regarded as an action or function of the *duration* of the loading.

"This elastic *after-effect* can easily be confused with *plasticity* of the fiber, which has been known for a long time, and which can be ascribed to small permanent changes in the state of aggregation of a solid body. The after-effect is, however, quite different from such a plasticity and can easily be differentiated in the observations. The difference lies, of course, in the nature of the above plasticity in that it occurs only on an increase of load, and never after a decrease of load. After an increase of load the after-effect is manifested as an *increase* in length dependent on the duration of loading. After a diminution of load, the after-effect appears as a decrease in length dependent on the duration of the recovery time. Experiment has shown that these opposite after-effects, the increase and the decrease in length, are the same for increase or decrease of load of the same magnitude."

Weber found that a previously untested filament, when subjected to loading for a few hours and subsequently unloaded, manifested a permanent set after creep recovery had ceased to take place. Upon repeating the experiment, he again observed a permanent set, but this time of smaller magnitude than in the first instance. On subsequent repetition of the test, no further permanent set was observable.

Concerning the delayed deformation in a "mechanically conditioned" specimen, Weber [14] remarked:

"Since, within definite limits of load, permanent set was henceforth excluded, the main experiment was carried out. The filament was held under load for 24 hours, and then quickly unloaded; it was measured before and after this rapid unloading. The difference in length thus obtained when compared with the similarly measured difference in load gave the modulus of elasticity. This part of the contraction depends directly on the decrease in load and consequently takes place simultaneously with it. The other part of the contraction, which up to the present has not been observed, continues noticeably for 24 hours. By the time this contraction is proceeding very slowly, it finally amounts to about one-third of the initial contraction in the case of silk filaments. It is thus too large to be disregarded. Moreover, this contraction is very slow over most of this period. At the beginning, however, it is large enough to be observed through the microscope and to be measured from minute to minute."

The literature [8, 2, 5] reveals an orthodox technique in the study of the creep properties of high polymers, wherein the irreversible deformations are eliminated by means of mechanical conditioning in order to facilitate the measurement of the delayed elasticity. Investigations of creep behavior have been directed mainly toward the development of fundamental concepts concerning the laws and mechanisms of deformation of high polymers in terms of the *ultimate structure* of materials.

Loads of a low order of magnitude have been employed, and the duration of the tests has usually been extended over periods of many hours, and, in some cases, days.

The results of these studies indicate the existence of three deformation components in interaction whenever a visco-elastic material is subjected to stress application. It is also indicated that the magnitude, rate, and type of load application have a definite effect upon the elastic performance of such a material. However, the literature reveals almost no data on the quantitative evaluation of these three deformation components for loads and loading conditions as these are generally imposed for the evaluation of end-use structures comprised of visco-elastic elements. It is generally agreed that research aimed toward scientifically evaluating material properties quantitatively for specific end-uses is greatly needed, especially in the field of textiles. The broad end-use requirement is durability. This "property" refers generally to the ability of a material to exhibit its original properties after repeated use. Thus, the reproducibility of stress-strain properties exhibited by a material following cyclical loading and unloading is highly desirable [7] and may be defined as its elastic performance [6].

The stress-strain diagram may be regarded as a resultant curve comprised of three component curves, each depicting one of the three deformation components—namely, (1) immediate elastic deformation, (2) delayed elastic deformation, and (3) non-recoverable deformation—the characteristics of which are dependent upon the type, magnitude, and rate of load application, or strain application, whichever is selected to be the independent variable in the testing.

The fact that the delayed deformations are critically dependent upon the test conditions points to the need for a technique for their determination which may be applied under conditions of dynamic loading or straining for various types and rates of loading or straining and for various magnitudes of load or strain from zero to that required to cause rupture. In addition to the determination of the delayed deformations, the technique must also provide adequate means for the determination of the immediate

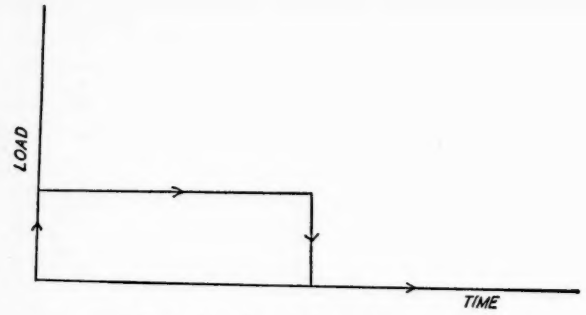



FIG. 1. *Load-time diagram.*

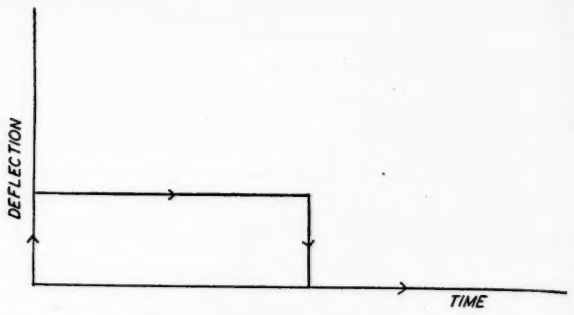



FIG. 2. *Deflection-time diagram (perfect elasticity).*

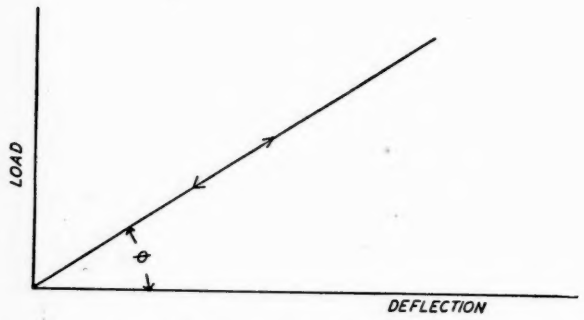



FIG. 3. *Load-deflection diagram (perfect elasticity).*

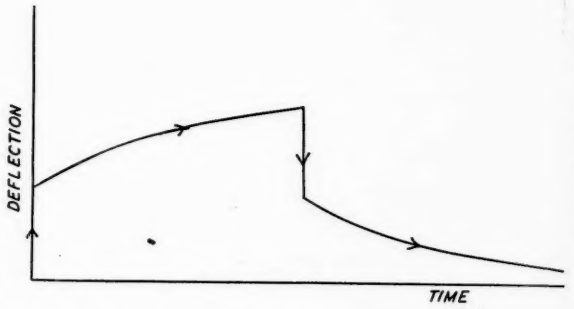



FIG. 4. *Deflection-time diagram (imperfect elasticity).*

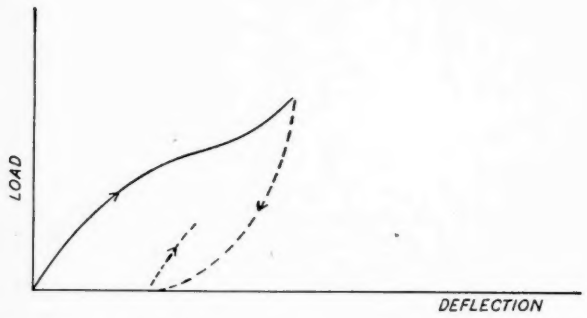



FIG. 5. *Load-deflection diagram (imperfect elasticity).*

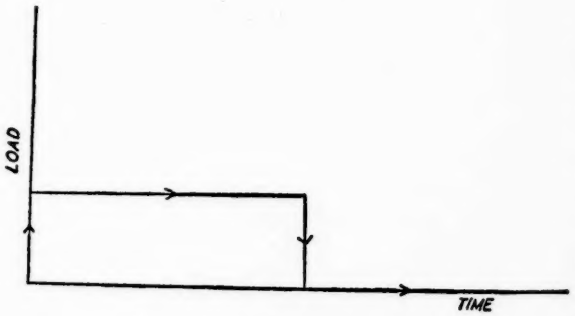



FIG. 6. *Load-time diagram.*

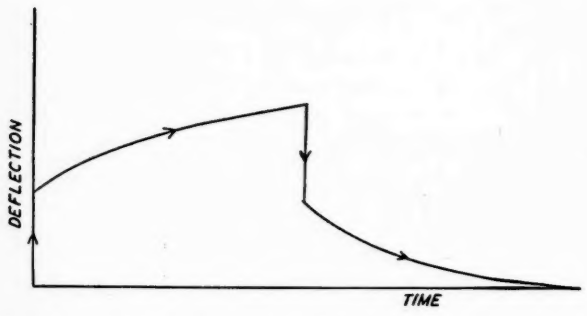



FIG. 7. *Deflection-time diagram (complete elasticity).*

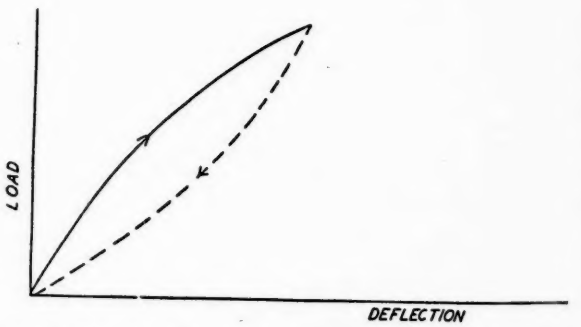



FIG. 8. *Load-deflection diagram (complete elasticity).*

elastic deformation under all the conditions indicated above. Thus, some means for analyzing the stress-strain curve is essential in order not only to determine the mechanism of elastic performance but also to evaluate quantitatively the elastic and plastic properties as they are affected by time as a dominant factor.

Geometrical analysis of repeated-stress diagrams has been employed [6] to determine coefficients of elastic performance of textile fibers and yarns, and coefficients which relate abrasion-resistance to stress-strain properties in tension [5, 7]. These coefficients have been calculated from geometric relationships which reflect the *influence* of modulus of elasticity, immediate elastic deformation, delayed elastic deformation, and non-recoverable deformation upon the stress-strain diagram without obtaining *quantitative* values for the modulus of elasticity and for each of the deformation components.

A complete quantitative analysis of repeated stress diagrams has not been attempted in the past, since no adequate means of evaluating the immediate elastic deformation and the delayed elastic deformation was available. The non-recoverable deformation has of course been determined by a simple unloading procedure.

## Techniques and Instrumentation

In view of the fact that some confusion exists in the minds of many investigators as to the existence of an absolutely non-recoverable deformation, certain definitions of terms used throughout this paper are essential. At this point, it should be pointed out that, because of the important influence of the time effect, all definitions which follow are considered to apply for the particular time cycle employed in any particular test, rather than for an indefinite time which might be selected, from zero to infinity. For these reasons, it has been deemed advisable to review certain concepts as they relate specifically to the visco-elastic behavior of materials.

When a load is impressed upon a material, it suffers deformation which may be divided into two major components, one taking place immediately, the other over a period of time. These components may be defined as follows:

1. Immediate elastic deflection—the deformation occurring at (a time approaching) zero time measured in (a time approaching) zero time.

2. Delayed deflection—the delayed deformation occurring in finite time and measured in finite time.

The second component, delayed deflection, may be further subdivided into recoverable and non-recoverable deformations, thus:

(*a*) Primary creep (delayed elastic, recoverable).

(*b*) Secondary creep (permanent set or plastic flow, non-recoverable).

Elasticity, or resilience, may be generally defined as the ability of a material to return to its original form or shape upon the removal of a previously applied load.

In order for a material to be *perfectly elastic* it must manifest no delayed deflections; that is, it must exhibit only immediate elastic deflection which permits it to recover immediately and completely upon load removal. Such perfectly elastic materials are represented by engineering materials at room temperature, for loads below the elastic limit.

Visco-elastic materials exhibit both primary and secondary creep deflections. When secondary creep is removed, a material exhibiting immediate elastic deflection and primary creep may recover completely in time, depending upon many factors affecting creep recovery. When a material recovers completely, although the recovery is delayed, it may be classed as *completely elastic,* in contrast to *perfectly elastic,* which connotes *immediate* and *complete* recovery.

If the delayed deflections were not present in visco-elastic materials, their action under load might be determined by some such technique as an instantaneous dead-loading procedure, since time would not be a dominant factor in evaluating performance from the standpoint of elasticity. The manifestation of primary and secondary creep, however, makes a consideration of the time effect of paramount importance.

Steel, at room temperature, for loads below the elastic limit, is an example of a perfectly elastic material. If load is applied at zero time and allowed to act for time $t$, and then removed, the load-time relationship may be indicated as in Figure 1.

The deflection-time relationship for such a material will be that shown in Figure 2.

Thus, the deflection is constant with time, and the specimen returns immediately and completely to its original form upon load removal, the magnitude of the deflection being proportional to the load. For these conditions, the load-deflection relationship is indicated in Figure 3.

or

$$E = \frac{d\left(\frac{P}{A}\right)}{d\left(\frac{\Delta L}{L}\right)_{\text{elastic}}} \quad ;$$

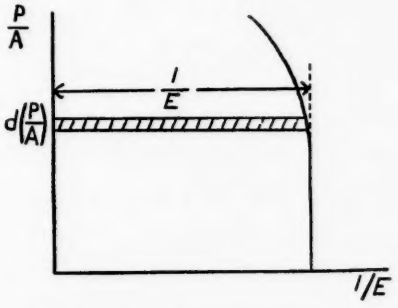
therefore

$$d\left(\frac{\Delta L}{L}\right)_{\text{elastic}} = \frac{d\left(\frac{P}{A}\right)}{E}$$

and

$$\int d\left(\frac{\Delta L}{L}\right)_{\text{elastic}} = \left(\frac{\Delta L}{L}\right)_{\text{elastic}} = \int \frac{d\left(\frac{P}{A}\right)}{E}.$$

Having a curve with load per unit cross-section area ($P/A$) as ordinate and the reciprocal of the instantaneous modulus of elasticity ($1/E$) as abscissa,




the integrand in the above expression is seen to be the differential element of area. Hence, the immediate elastic deflection for a stress corresponding to a given instantaneous modulus of elasticity may be calculated as the area under a stress versus $1/E$ curve up to the load in question.

It now becomes obvious that one of the two unknown deformation components, immediate elastic deflection, can be determined. With the secondary creep value available from an unloading procedure, the primary creep deflection for any load may be calculated by difference:

Tot. Defl. − II Creep − I.E.D. = I Creep,

where Tot. Defl. = total deflection, I.E.D. = immediate elastic deflection, I Creep = primary creep deflection, and II Creep = secondary creep deflection.

There now remains the necessity for a technique for the determination of the instantaneous modulus of elasticity for any given stress or strain.

It can be demonstrated from the theory of elasticity that the modulus of elasticity bears a relationship to the density of and the velocity of wave propagation in an elastic medium [13]. For example, when a prismatic bar is set into longitudinal vibration by mechanical, sonic, or other means, its axis remains undisplaced but its cross sections vibrate in the direction of the axis of the bar.

Consider a bar, of cross section $A$, and an element of it, bound by two planes at $x$ and $x + dx$, respectively, at right angles to the axis $x$ of the bar. If the plane at $x$ is displaced at time $t$, as a result of the vibrations, to $x + u$, the plane at $x + dx$ will be displaced to $x + dx + u + \frac{\partial u}{\partial x} dx$. Thus, the actual elongation of the element is $\frac{\partial u}{\partial x} dx$ and its fractional elongation is $\frac{\partial u}{\partial x}$. This change in thickness of the element indicates a difference between the forces acting on its faces.

The total force acting at $x$ will be $EA \frac{\partial u}{\partial x}$, where $E$ is the instantaneous modulus of elasticity. At the opposite face of the element, the force will be acting in the opposite direction and will be equal to $EA\left(\frac{\partial u}{\partial x} + \frac{\partial^2 u}{\partial x^2} dx\right)$. The resultant force acting on the element will be $EA \frac{\partial^2 u}{\partial x^2} dx$.

The mass of the element of the bar of cross section $A$ and density $\rho$ is $A\rho dx$. The acceleration is $\frac{\partial^2 u}{\partial t^2}$, and therefore the equation of motion is

$$A\rho dx \frac{\partial^2 u}{\partial t^2} = EA \frac{\partial^2 u}{\partial x^2} dx$$

or

$$\frac{\partial^2 u}{\partial t^2} = \frac{E}{\rho} \frac{\partial^2 u}{\partial x^2}.$$

It can be shown from the solution of this differential equation that $v^2 = \frac{E}{\rho}$, and that therefore

$$v = \sqrt{\frac{E}{\rho}},$$

where $v$ is the velocity of propagation of waves in the prismatic bar.

Solving for $E$:

$$E = v^2 \rho.$$

With this relationship as a basis and by the use of sonic means, Ballou and Silverman developed a method and apparatus for the determination of the sonic moduli of various materials in filamentous and

For *perfectly elastic* materials, then, the load-deflection relationship is linear, and materials manifesting perfect elasticity vary from one another elastic-wise only as do their "stiffness" or "softness"—that is, their modulus of elasticity, which is represented as tan $\theta$, in Figure 3.* The shape of the load-deflection diagram is unchanged—always remaining a straight line inclined at some angle to the deflection axis, up to the elastic limit.

In a material which is *imperfectly elastic,* the three components of deflection exist in interaction, and the shape of the load-deflection diagram is the result of the interaction of these three components.

If a load is applied to such a material at zero time and allowed to act for time $t$, and then removed, the load-time relationship is that shown in Figure 1.

However, in contrast to the similarity of load-time relationships between perfectly and imperfectly elastic materials, the deflection-time relationship differs because of the presence of the delayed components. This difference is shown in Figure 4 (compare with Figure 2).

The deflection is not constant with time. In this case, there exists an immediate elastic deflection which is proportional to the load and a delayed deflection which increases at a decreasing rate with time. Upon load removal, there is an immediate elastic contraction, and a delayed contraction which increases at a decreasing rate with time. The recovery is not complete, however, and the material does not return to its original (unloaded) condition. This failure to return is a function of the magnitude of secondary creep manifested by the material.

A typical load-deflection diagram for such a material is that for acetate rayon (Figure 5).

The load-deflection diagram is not linear, since the delayed components affect its shape. Hence, it is important to consider the shape of the diagram in determining any index of elastic performance for non-linear materials such as textile fibers and structures.

For the example just cited, the specimen does not return to its original condition because of the presence of secondary creep. This component may, for all practical purposes, be removed by repeated load application and removal, leaving only the immediate elastic deflection and the primary creep deflection as a result of such procedure.

Consider the load-time relationship for such a mechanically conditioned (secondary creep absent) material (Figure 6).

The deflection-time relationship is indicated in Figure 7, and the load-deflection relationship is shown in Figure 8.

The deflection, in this case, is not constant with time, but the recovery is complete, although delayed as a result of the primary creep component. Similarly, the deflection is not linear with load, since the delayed component (primary creep) is acting in addition to the immediate elastic component.

It may now be observed that, from the nature of typical original load-deflection curves obtained experimentally for the behavior of visco-elastic materials, these materials are imperfectly elastic, since the curves obtained reflect the summation of the effects of all three deflection components—immediate elastic, primary creep, and secondary creep.

The average modulus of elasticity is the ratio of total stress to total strain (not necessarily *elastic strain*) as determined graphically from the slope of the stress-strain curve. For a perfectly elastic material, the average modulus of elasticity and the instantaneous modulus of elasticity are identical, since any increment of strain along the stress-strain diagram is elastic strain.

The instantaneous modulus of elasticity is the ratio of total stress to *elastic strain* resulting from a load applied in (a time approaching) zero time and measured in (a time approaching) zero time. Since the stress-strain diagram for an imperfectly elastic material is comprised of the immediate elastic deflection and delayed deflection, the instantaneous modulus cannot be determined by graphical methods from such a stress-strain diagram. It has been stated that the stress-strain curve of a visco-elastic material may be regarded as a resultant curve of three component curves, each depicting one of the three deformation components, and that only one of these, the secondary creep deflection, readily lends itself to quantitative evaluation. Thus, it appears that two unknowns remain to be determined, the immediate elastic deflection and the primary creep deflection.

The relationship of stress to strain in a perfectly elastic body is represented by Young's modulus $E$, which may be defined as the ratio of the stress increment to the elastic strain increment:

$$E = \frac{\text{stress increment}}{\text{elastic strain increment}}$$

* Length and cross-sectional area must be known in order to derive a true modulus.

For a material in which viscosity is not negligible, the effective modulus is not independent of frequency; therefore, for such a material a dynamic measurement of modulus is not a substitute for a static measurement. If the viscous contribution is not too large, however, it may be reasonable to assume that the static modulus is essentially proportional to the dynamic modulus, even though the two are not identical.

Rough observations, at a frequency of 10,000 cycles per second, on nylon indicate that the correction necessary for the simple modulus formula is no greater than $E = .95\rho v^2$, and for acetate the correction is approximately $E = .98\rho v^2$. Hence, correction for acoustical attenuation was neglected in this research, where the Ballou and Silverman apparatus and modifications of it were employed.

In applying the sonic method of wave propagation to the determination of immediate elastic deflections of visco-elastic materials, it is assumed that the effect of the stresses and strains set up in the material as a result of the propagation of sound waves through it are of a sufficiently low order of magnitude to preclude the creation of any delayed after-effects. This appears to be a reasonable assumption since the delayed elastic after-effects are dependent upon duration and magnitude of load or strain application.

With the standing wave technique of Ballou and Silverman, there also exists the possibility that the effects of forces of opposite sense will create a superposition effect which would cancel out any possible manifestation of delayed after-effects, should the loads or strains imparted to the specimen by such standing waves be of sufficient magnitude to introduce delayed deformations.

Early in this work there was developed a concept of an "absolute" modulus of elasticity of visco-elastic materials which was considered to exist when the material is placed in an environment where, upon application of external forces or strains, only a perfectly elastic mechanism can prevail.

Such a situation might prevail for high polymers under conditions where both Brownian movements are frozen and where the material exists in a crystalline solid state [9]. The modulus of elasticity of a material in this state should be constant for loads up to the elastic limit, as is the case with metals.

Thus, it can be argued that in an ordinary environment visco-elastic materials manifest a "dependent" modulus of elasticity, the variation of which is dependent upon the influence of their visco-elastic behavior upon their stress-strain-time-temperature-humidity relationships. Only the effects of load, strain, and time at a constant temperature (70°F) and relative humidity (65% R.H.) have been investigated in this research.

Two types of tests were initially conducted for the purpose of evaluating the modulus of elasticity of textile fibers and yarns by sonic means: (1) separate loading and (2) progressive loading.

Separate loading signifies that a new specimen with no known previous loading history is used for the determination of each value of modulus corresponding to a given load.

Progressive loading signifies that the specimen has been loaded continuously over the range of the test. That is to say, the sample is subjected to an initial load, and then a time (1 minute) is allowed for apparent equilibrium to occur, whence the load is increased by selected load increments in accordance with the selected time schedule until rupture occurs or some given load is reached.

These tests were conducted at a fixed frequency of 10 KC per second, in accordance with the procedure previously described. The data will be presented and discussed in a subsequent section.

Both the separate and the progressive loading techniques involve a discontinuous loading procedure which involves certain undesirable features. It is difficult, if not impossible, to apply or increase the loading without impacting the specimen to some extent. As a result, the reproducibility of data is somewhat questionable. Continuity of loading at any prescribed rate is impossible.

Since it was desired to determine the modulus under various laboratory loading and straining conditions, an autographic procedure for its determination was developed as a modification of the original apparatus. In this procedure, the specimen was placed in the jaws of a Scott I-P-2 constant-rate-of-load tensile testing machine, and the crystals were mounted on the extension of the rod on which the loading carriage rolls. The crystal separation was held fixed at a predetermined value roughly equivalent to the half wave length of sound in the specimen, corresponding to a frequency of 10,000 cycles per second. As the specimen was uniformly loaded, the closed figure on the oscilloscope screen was kept closed by varying the frequency. The dial on the oscillator which controls the variation of frequency was pulley-connected to the pen of a recorder, the chart of which travels at a constant rate. Thus, time

sheet form [1]. The apparatus for such determinations consists of the following parts:

1. A high-frequency oscillator capable of producing vibrations of the order of magnitude of 10,000 cycles per second.

2. A distortion-free rochelle salt crystal which receives the vibrations from the oscillator and by contact transmits them to the specimen, setting up standing longitudinal compression waves in the specimen of the same frequency as those of the oscillator output.

3. A second mounted rochelle salt crystal which is also in contact with the specimen and which is activated into vibration by the vibrating specimen at the same frequency as the oscillator. This crystal is called the "output" crystal, whereas the crystal mentioned previously is called the "input" crystal.

4. A cathode-ray oscilloscope which receives the wave form of both the input and output crystals. These two waves are always of the same frequency, but in general they are of different amplitudes and are not, except for certain positions of the output crystal relative to the input crystal, in phase with each other.

5. A graduated bench, along which the output crystal can be moved, which allows the distance between the two crystals to be determined at any time during the test. The sonic apparatus permits a rapid and accurate determination of the instantaneous modulus of elasticity.

The density $\rho$, which is the same as the specific gravity when expressed in metric units, is known rather precisely for textiles. The test gives the value for $v$, the velocity of sound through the material, in the following manner. A given frequency of "$f$" cycles per second is sent from the oscillator through the specimen. Both input and output wave forms appear on the oscilloscope screen. Whenever the two wave forms are an integral number of half wave lengths different in phase, a straight-line diagram is produced on the oscilloscope screen. Therefore, while a fixed position of the input crystal is maintained, the output crystal is moved along the graduated bench, and the readings corresponding to the straight-line diagrams are recorded. The differences between all consecutive readings give values of the half wave lengths, $l_2 - l_1$, throughout the length of the sample, and the values are averaged. Now with the frequency "$f$" known, and the wave length of sound $2(l_2 - l_1)$ determined, the velocity of sound is known to be

$$v = f\,2(l_2 - l_1),$$

where

$f$ = frequency in cycles/sec.

and

$2(l_2 - l_1)$ = wave length in cms.

Substituting this value of velocity into the expression for modulus,

$$E = 4f^2(l_2 - l_1)^2\rho,$$
$$E = f^2\lambda^2\rho,$$

where $\lambda$ = wave length in cms.

For convenience in converting to other units, the following conversion factors are given:

$E$ in pounds per square inch $= 1.45 \times 10^{-5} \times E$, in $\frac{\text{dynes}}{\text{cm.}^2}$

$E$ in grams per denier $= 1.136 \times 10^{-9}v^2$, where $v$ is expressed in cms./sec.

By this technique for the determination of the instantaneous modulus of elasticity by sonic means, the measurement is made in 50 $\mu$ seconds, which may be considered to be a value approaching zero time when compared with elapsed time, as measured by orthodox laboratory procedures.

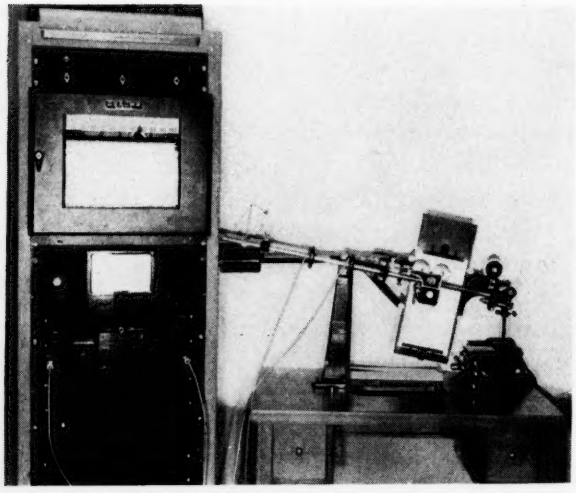
The relationship $E = v^2\rho$ holds precisely only when the propagating medium is perfectly elastic. If a material exhibits appreciable acoustic attenuation, there is a significant amount of viscosity associated with the modulus, and additional information is necessary for a precise determination of its value. The viscosity is defined here as a quantity the value of which is identical with the value for Young's modulus, except that the viscous force depends upon the time rate of change of strain rather than upon the strain itself. The viscosity coefficient may be found from the same information required for the computation of Young's modulus [10].

In this case

$E = \rho v^2(1 - r^2)/(1 + r^2)^2$ dynes/cm.$^2$
$= \rho v^2(2r)/(1 + r^2)^2(2\pi f)$ dynes-sec./cm.$^2$ (viscosity coefficient),

where

$r = \alpha\lambda/2\pi$
$\lambda$ = wave length in cms.
$f$ = frequency in cycles/sec.
$\alpha$ = attenuation in nepers/cm.
$= \frac{\text{attenuation in db/cm.}}{8.686}$



*Photograph of the Pulse Propagation Meter.*

and frequency are the coordinates of this semi-autographic plot. Since the rate of chart travel and the rate of loading of the I-P-2 machine are both known, the value of the frequency corresponding to a half wave length of sound through the specimen can be obtained as a function of load. This autographic procedure is advantageous for the following reasons:

1. The modulus is determined directly as the specimen is loaded. This simplifies relationships concerned with the time effect.

2. The method is smoother in operation than the stepwise-loading procedure previously described.

3. A graphical representation of the effect of load on the modulus is obtained.

It is, of course, obvious that a similar combination of sonic apparatus with constant-rate-of-extension testers is also possible.

The above-described autographic procedure employs a fixed-path, variable-frequency method as contrasted with the fixed-frequency, variable-path method described and used for the initial tests conducted in this work; and while this modification of the original technique has its advantages, it leaves much to be desired in obtaining data of satisfactory accuracy and reproducibility.

The fixed-path, variable-frequency conditions of the semi-autographic technique introduce two serious sources of error: (1) end-effects (which are also present in the original Ballou and Silverman technique) resulting from the reflection of waves from the two end fixtures which support the specimen, and (2) phase shifts which occur at unpredictable periods during the conduct of the tests. These phase shifts are a function of the resonant frequency of the crystals and of the frequency range employed. Since the frequency range necessary for the test is dependent upon the range of modulus values of the material under stress or strain, it is obvious that preliminary calibration tests must be run to eliminate the possibility of such phase shifts and the attendant errors resulting therefrom. The crystal spacings must be modified to permit a dependable range of frequencies to be employed. Such a procedure increases the absolute magnitude of acoustical attenuation where crystal separations are increased, and increases the end-effects where crystal separations are decreased to eliminate the shifts of phase.

Thus a means of measurement which would be independent of these two major limitations became essential. This problem was submitted to the consulting staff of the Magnetic Amplifier Corporation of Waltham, Massachusetts, for their consideration. Messrs. A. A. Janszen and S. R. Rich of this staff then proposed and demonstrated the practicability of the pulse-propagation principle as a means of achieving a measuring technique which would be free of the limitations inherent in the older systems. As a result of a successful demonstration, the Magnetic Amplifier Corporation was engaged to develop an instrument, based upon their new technique, to meet performance specifications required in the research reported in this dissertation. This "Pulse Propagation Meter," or "PPM," as it is called, sends pulses of less than a micro-second duration through the specimen, and their times of arrival at the receiving crystal are individually and precisely measured. These pulses are transmitted at the rate of 160 per second. This rate of transmission is sufficiently low to permit the amplitude of each pulse to decay to zero before the initiation of the next succeeding pulse. Thus, no standing waves are set up in the specimen.

Since the time of arrival of each pulse at the receiving crystal is measured separately, no end-effects are developed; and because standing waves are not set up in the specimen and frequencies are not involved, phase shifts are not a consideration.

It is evident that only the time of propagation of a pulse through the medium is measured by this instrument. The crystals may be spaced any desired distance apart, depending upon the available specimen length and/or the range of time units (in

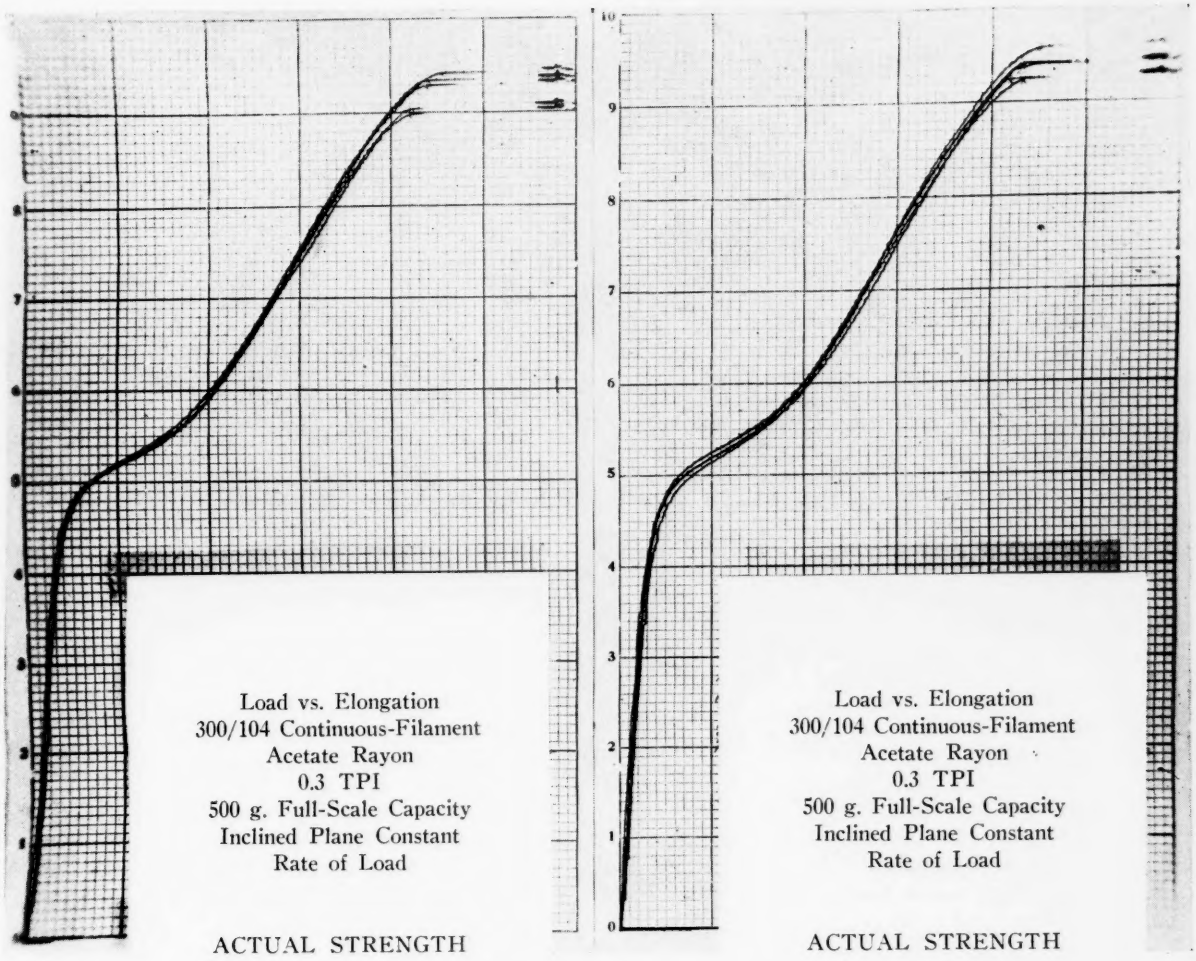



FIG. 9.

seconds) most convenient for plotting and for the analysis of data.

The output of the pulse propagation meter is fed into a squaring autographic potentiometer, which draws a curve of the reciprocal of time squared versus load or deformation, depending upon the type of testing device employed in combination with it. Thus, it is seen that values of $1/E$ versus load or deformation may be obtained from the plot of $1/t^2$ versus elapsed testing time by the application of proper constants to account for crystal separation and chart scales.

Data obtained with this instrument will be presented and discussed in a subsequent section, in comparison with the two methods previously described.

### Experimental Procedure and Data

The data collected in this research may be divided with respect to source into three major parts:

Part 1. Dead-loading procedure.

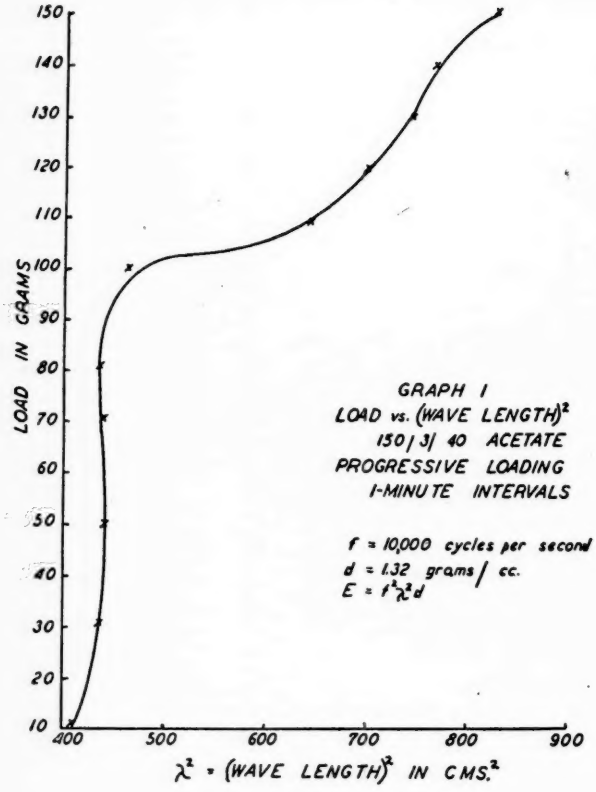
Part 2. Semi-autographic continuous-loading procedure.

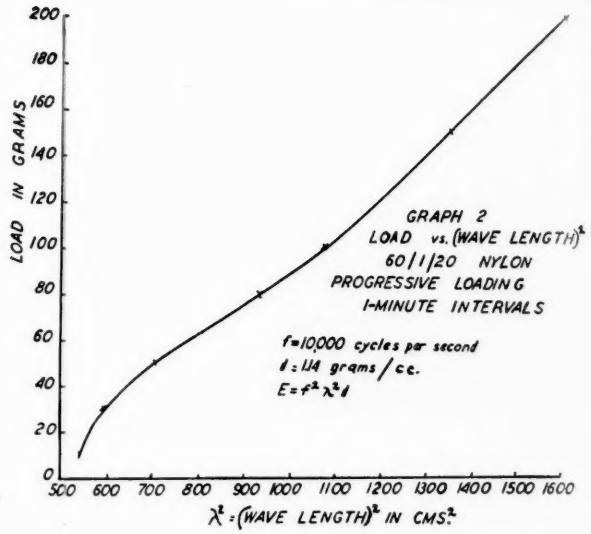
Part 3. Pulse-propagation procedure.

Part 1. The specimen was subjected to stress by application of a dead load in accordance with the separate-loading and progressive-loading techniques. The half wave length of sound transmitted by the material was determined at a fixed frequency of 10 KCS by means of varying the length of the path between crystals.

Part 2. The specimen was subjected to stress applied by a conventional Scott I-P-2 tensile tester. The path, or distance between crystals, was held fixed and the frequency was varied. In contrast to Part 1, the resonant frequency of vibrations in the specimen corresponding to a half wave length equal to the crystal spacing was measured by this method.

Part 3. The pulse propagation meter was em-




ployed in conjunction with conventional tensile-testing equipment, such as the I-P-2 machine for constant-rate-of-load application and an electronic strain-gage type of tensile tester for constant-rate-of-elongation testing.

Textile yarns of acetate rayon, viscose rayon, and nylon were selected as representative of the various types of synthetic polymeric fibers most generally in use in the textile field. Each material was investigated by means of one or all of the methods described above, as the requirements of the research dictated.

*Part 1. Dead-Loading Procedure*

*Materials Investigated*

Tennessee Eastman Acetate Rayon
300 denier, 104 filaments, containing 0.3, 1.5, 3, 6, 12, and 24 turns per inch of twist

DuPont Nylon Type 300
60 denier, 20 filaments, containing 1 turn per inch of twist

DuPont Nylon Type 300
210 denier, 69 filaments, containing 2, 4, 6, 8, and 10 turns per inch of twist

DuPont Nylon
Undrawn 1030/34/1Z–400, partially drawn 550/34/1Z–400, fully drawn 200/34/1Z–400

Acetate 150/3/40 (Celanese)

Viscose 150/3/40 (American Viscose)

Nylon 60/1/20 unshrunk

Nylon 60/1/20 shrunk by steam at 250°F for 30 minutes

Table I and Table II give typical test results for acetate 150/3/40 and nylon 60/1/20, respectively. The samples were subjected to progressive loading, allowing a 1-minute interval for equilibrium to occur between successive additions of load increments. The data from Tables I and II are plotted on Graphs 1 and 2 and depict the relationship between $\lambda^2$ in square centimeters and load in grams.

In order to determine the reproducibility of and the significance of differences between values obtained from the application of sonic techniques to textile materials, six constructions of acetate 300/104 yarn were investigated by means of both the separate- and the progressive-loading procedures. Values of the square of the wave length of sound, $\lambda^2$, versus load were determined for yarns containing the twist per inch as previously listed. The individual data are given in Tables III and IV, and averages of values so obtained are plotted in Graphs 3 and 4.

In the separate-loading procedure, a new specimen was used for each value of $\lambda^2$ corresponding to a given load. Thus, one sample was loaded, a minute was allowed to elapse for equilibrium to oc-

TABLE I. WAVE LENGTHS FROM PROGRESSIVE LOADING PROCEDURE FOR 150/3/40 CONTINUOUS-FILAMENT ACETATE RAYON

$f$ = 10,000 c.p.s. Input = 2 volts. 1-minute progressive loading intervals.

| | Values of $\lambda/2$ (in cm.) for load of: | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 g. | 30 g. | 50 g. | 70 g. | 80 g. | 100 g. | 110 g. | 120 g. | 130 g. | 140 g. | 150 g. |
| | 10.0 | 10.5 | 10.50 | 10.50 | 10.45 | 10.90 | 12.80 | 13.3 | 13.70 | 13.9 | 14.5 |
| | 10.2 | 10.5 | 10.55 | 10.50 | 10.45 | 10.65 | 12.70 | 13.2 | 13.60 | 13.8 | — |
| | 10.1 | 10.5 | 10.55 | 10.50 | 10.50 | 10.80 | 12.80 | 13.2 | — | — | — |
| | 10.0 | 10.4 | 10.40 | — | 10.40 | 10.70 | 12.40 | 13.1 | 13.55 | 13.8 | 14.2 |
| | 10.3 | 10.5 | 10.50 | 10.50 | 10.45 | 10.80 | 12.70 | 13.2 | 13.65 | 13.8 | — |
| | 10.0 | 10.5 | 10.50 | 10.45 | 10.40 | 10.64 | — | — | — | — | — |
| Ave. $\lambda/2$ cm. | 10.1 | 10.46 | 10.50 | 10.49 | 10.44 | 10.75 | 12.68 | 13.2 | 13.62 | 13.82 | 14.25 |
| Ave. $\lambda$ cm. | 20.2 | 20.92 | 21.0 | 20.98 | 20.88 | 21.50 | 25.36 | 26.40 | 27.24 | 27.64 | 28.50 |
| Ave. $\lambda^2$ cm.$^2$ | 408.04 | 437.65 | 441.00 | 440.16 | 435.97 | 462.25 | 643.13 | 696.96 | 742.02 | 763.97 | 812.25 |

TABLE II. WAVE LENGTHS FROM PROGRESSIVE LOADING PROCEDURE FOR 60/1/20 CONTINUOUS-FILAMENT NYLON

$f$ = 10,000 c.p.s. Input = 2 volts. 1-minute progressive loading intervals.

| | Values of $\lambda/2$ (in cm.) for load of: | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10 g. | 30 g. | 50 g. | 80 g. | 100 g. | 150 g. | 200 g. |
| | 11.5 | 12.1 | 13.1 | 15.0 | 16.5 | 18.1 | 20.0 |
| | 11.7 | 12.2 | 13.3 | 15.3 | 16.4 | 18.5 | 20.2 |
| | 11.8 | 12.3 | 13.5 | 15.5 | 16.6 | 18.6 | 20.0 |
| | 11.6 | 12.1 | 13.3 | 15.3 | 16.1 | 18.3 | 20.0 |
| Ave. $\lambda/2$ cm. | 11.65 | 12.18 | 13.30 | 15.28 | 16.40 | 18.38 | 20.05 |
| Ave. $\lambda$ cm. | 23.30 | 24.36 | 26.60 | 30.56 | 32.80 | 36.76 | 40.10 |
| Ave. $\lambda^2$ cm.$^2$ | 542.89 | 593.41 | 707.56 | 933.91 | 1,075.84 | 1,351.30 | 1,608.01 |

cur, and the wave length was determined. Another sample was then employed for the next determination. In such a test, the sample tested is one which has no planned, previous loading history.

It is to be noted from both sets of curves that the modulus of elasticity (represented by $\lambda^2$) is fairly constant in the low regions of load, up to about 0.5 gram per denier, for all twists except the very high twist of 24 t.p.i. Following this load, the modulus apparently increases rapidly with increase in load, indicating a decrease in the increment of the immediate elastic component of deflection with increments of load. In general, there seems to exist a trend for values of the modulus to decrease with twist for loads up to 0.5 gram per denier for both separate and progressive loading, following which all twists seem to yield essentially equal moduli. The lower values of moduli for high twists indicate greater immediate elastic deflections and may be explained by the analogous fact that a metal wire showing *small* extensions when stressed axially will show much greater extension when formed into a helical spring. Since the modulus is the ratio of the axial stress intensity to elastic axial strain, then it is apparent that a high-twist material would show a lower modulus merely as a form effect.

Comparison of *separate* versus *progressive* loading procedures indicates but little difference for all twists up to 0.5 gram per denier regardless of the method of loading used. Following this load, there is a very slightly greater value of the modulus for separate loads.

Statistical analyses, made to test the significance of differences of the above moduli, are included in the following pages.

The textile specimens utilized for analyses in this research were taken from pedigreed control stock which had been carefully characterized over a period of from 1 to 3 years. As a result, it is felt that presentation of typical test results is justified, since the degree of variability of the materials has already been satisfactorily established. Illustrative of the uniformity of load-elongation results are the curves of 300/104 acetate, 0.3 t.p.i., yarns, 10 of which are represented on Figure 9.

Table V tabulates data taken on nylon yarn, type 300, 210 denier, 69 filaments, containing 2, 4, 6, 8, and 10 turns per inch of twist. In this case, the

TABLE III. AVERAGE WAVE LENGTHS SQUARED (cm.)²* FROM PROGRESSIVE LOADING PROCEDURE FOR 300/104 CONTINUOUS-FILAMENT ACETATE

$f$ = 10,000 c.p.s. Input = 2 volts. 1-minute progressive loading intervals.

| T.P.I. | 20 g. | 50 g. | 80 g. | 100 g. | 125 g. | 150 g. | 175 g. | 200 g. | 225 g. | 250 g. | 275 g. | 300 g. | 325 g. | 350 g. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.3 | 460.53 | 468.29 | 466.56 | 463.97 | 463.11 | 461.39 | 468.29 | 488.41 | — | 725.76 | — | 823.69 | — | 944.95 |
| 1.5 | 460.53 | 463.11 | 460.53 | 461.39 | 457.10 | 456.25 | 462.25 | 500.86 | 625.00 | 708.62 | — | 819.10 | — | 933.91 |
| 3.0 | 457.99 | 456.25 | 458.82 | 457.10 | 456.25 | 453.69 | 463.97 | 496.40 | 624.00 | 700.13 | — | 827.14 | 883.28 | 926.59 |
| 6.0 | 417.79 | 446.05 | 450.29 | 449.44 | 448.59 | 447.75 | 454.54 | 489.29 | 613.06 | 690.64 | 749.66 | 792.99 | 858.49 | — |
| 12.0 | 372.49 | 400.80 | 404.81 | 406.43 | 414.53 | 421.89 | 440.16 | 506.25 | 617.03 | 690.64 | 748.57 | 792.99 | 847.97 | — |
| 24.0 | 257.92 | 297.91 | 301.37 | 326.16 | 340.77 | 374.81 | 431.81 | 492.84 | 576.96 | 632.02 | 696.96 | — | — | — |

* Average of 12 readings.

TABLE IV. AVERAGE WAVE LENGTHS SQUARED (cm.)²* FROM SEPARATE LOADING PROCEDURE FOR 300/104 CONTINUOUS-FILAMENT ACETATE

$f$ = 10,000 c.p.s. Input = 2 volts. 1-minute intervals.

| T.P.I. | 25 g. | 50 g. | 80 g. | 100 g. | 125 g. | 150 g. | 175 g. | 200 g. | 225 g. | 250 g. | 275 g. | 300 g. | 325 g. | 350 g. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.3 | 469.16 | 470.89 | 469.16 | 469.16 | 464.83 | 461.39 | 464.83 | 504.45 | 650.25 | 732.24 | 798.63 | 862.01 | 924.16 | 979.69 |
| 1.5 | 456.25 | 462.25 | 461.39 | 458.82 | 457.96 | 456.25 | 462.25 | 515.29 | 637.06 | 733.33 | 798.63 | 851.47 | 910.83 | — |
| 3.0 | 453.69 | 459.67 | 460.53 | 457.96 | 457.10 | 455.40 | 462.25 | 509.86 | 640.09 | 726.84 | 794.11 | 850.31 | 907.21 | — |
| 6.0 | 412.90 | 442.68 | 440.16 | 452.84 | 453.69 | 446.05 | 455.40 | 489.29 | 621.01 | 718.24 | 767.29 | 841.00 | 901.20 | — |
| 12.0 | 360.24 | 400.80 | 404.81 | 406.43 | 409.66 | 416.98 | 434.31 | 500.86 | 613.06 | 703.31 | 765.08 | 829.44 | 888.04 | — |
| 24.0 | — | 286.29 | 304.15 | 304.85 | 334.16 | 367.87 | 429.32 | 519.84 | 606.14 | 659.46 | 719.31 | — | — | — |

* Average of 12 readings.

following way. The decreasing modulus may be ascribed to the stretching of the chains in the transition $\alpha$–$\beta$-keratin. The increasing modulus corresponds to the bending of valence angles in the straight $\beta$-keratin chains.

Table VII and Graph 7 compare the modulus-load relationship for acetate 150/3/40, viscose 150/3/40, nylon 60/1/20 unshrunk, and nylon 60/1/20 shrunk for 30 minutes in steam at 250°F. The values of $1/E$ are plotted versus load in grams. From the graph it may be observed that the nylon diagrams are of a characteristically different shape from those for the acetate and viscose, there being no portion in which the modulus remains constant with an increase in load, and also no sharply defined yield point, as is the case for the acetate and viscose.

The dotted lines from the abscissa indicate that no data were available for loads below those reported for the respective materials. However, later work indicates that nylon manifests no constant modulus even at very low loads.

The initial modulus for nylon is somewhat greater than that for acetate, but less than the initial modulus for viscose. It is interesting to note that the increase in the modulus of nylon resulting from increasing the load is greater percentage-wise as well as on an absolute basis than that for viscose. Also worthy of note is the fact that nylon attains a higher value of modulus than does viscose, even though its initial modulus is below that of viscose.

*Part 2. Semi-Autographic Continuous-Loading Procedure*

*Materials Investigated*

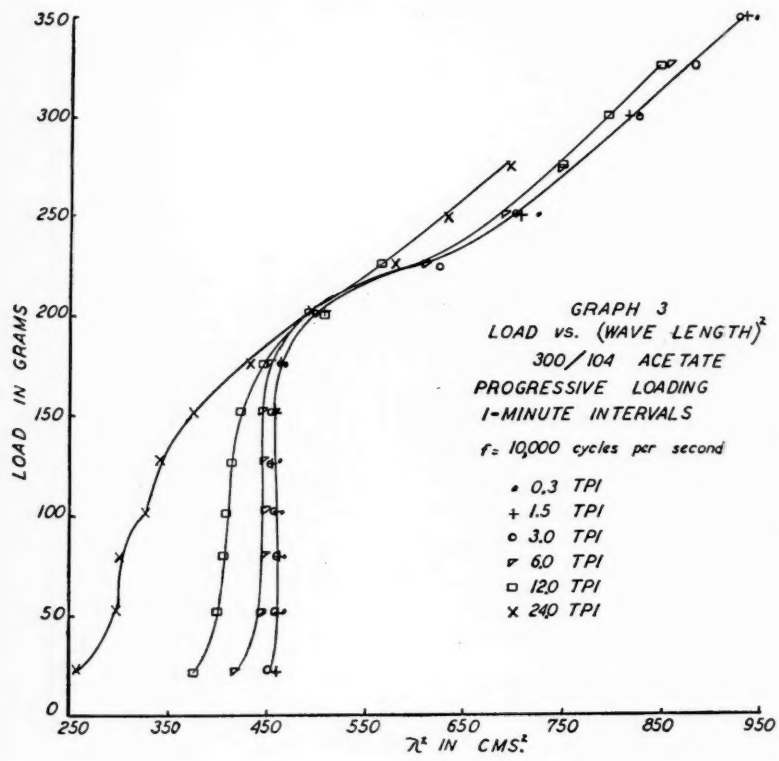
Tennessee Eastman Acetate Rayon
300 denier, 104 filaments, containing 0.3, 1.5, 3, 6, 12 and 24 turns per inch of twist

Tennessee Eastman Acetate Rayon Staple
Yarns constructed from 1½-inch and 2½-inch staple, each containing 11, 15, 19, 23, and 26 turns per inch of twist

Five specimens of filamentous acetate rayon yarn of each twist as noted above were tested by the semi-autographic, continuous-loading procedure. Table VIII, for load versus $1/E$, represents the data for this material. An average curve for load versus modulus of elasticity, $E$, was constructed for each twist. These curves are given on Graph 8.

The results indicate that, in general, the higher the twist the lower the modulus of elasticity. There were no significant differences in moduli among the 0.3, 1.5, 3, and 6 t.p.i. yarns. The greatest differences exist when the high twists of 12 and 24 t.p.i. are encountered. It is interesting to observe that the 0.3 through 6 t.p.i. yarns showed a modulus

value $1/E$ is plotted versus load in grams on Graph 5. The uniformity of the nylon is obviously greater than that of the acetate indicated on Graphs 3 and 4. The higher twists yield lower moduli for nylon at the lower loads, as was the case for acetate. However, at higher loads, the yarns of various twists more nearly approach a common modulus than did the acetate. This may be explained by the facts that the twists and helix angles are of lower orders of magnitude and that nylon's longer-range elasticity permits a better adjustment of its filaments to form a more homogeneous yarn structure, thereby introducing less form effect upon the modulus.



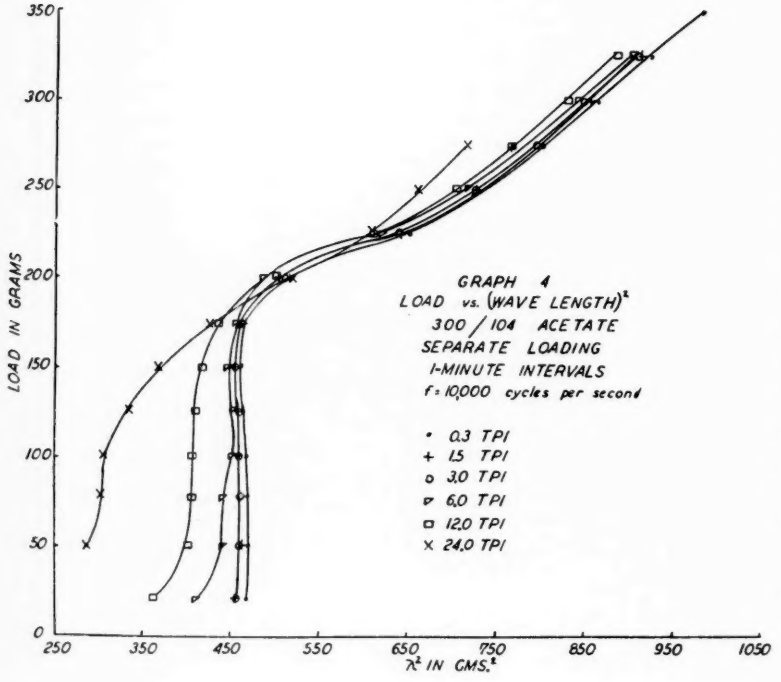




Table VI and Graph 6 represent data obtained from undrawn nylon, type 400, 1030 denier, 34 filaments, 1 turn per inch of twist; partially drawn nylon, 550 denier, 34 filaments, 1 turn per inch of twist; and fully drawn nylon, 200 denier, 34 filaments, 1 turn per inch of twist. The value $1/E$ is again plotted versus load in grams.

It is to be noted that drawing sharply increases the modulus and that the curves of the undrawn and the partially drawn specimens tend, with increases of load, to approach and join with the curve of the fully drawn material. This might well be expected, since the commercial drawing procedure subjects the material to a straining action similar to that created in the course of the test procedure employed in this investigation.

The reversal in modulus in the early portion of the loading cycle for the undrawn material is interesting. Its cause is not entirely clear. However, Woods indicates the possibility of a change of entropy occasioned by a local disorientation which first takes place upon stress application [15]. Possibly, as a result of the unfolding of a chain folded back on itself, and then of a further straightening of the chain and an increase in orientation, a reversal takes place and an increase in modulus continues.

Chevenard and Champetier [3] observed a similar phenomenon in their investigation of the elastic modulus of human hair, which they explain in the

TABLE V. MODULUS OF ELASTICITY FROM PROGRESSIVE LOADING DATA FOR NYLON TYPE 300, 210 DENIER, 69 FILAMENT

$f$ = 10,000 c.p.s. Input = 2.0 volts.
1 = minute intervals
Values of $E^*$ for loads of:

| Twist T.P.I. | 120 g. | 225 g. | 350 g. | 450 g. | 675 g. | 800 g. |
|---|---|---|---|---|---|---|
| 2 | 79.8 | 101 | 128 | 151 | 191 | 212 |
| 4 | 79.8 | 101 | 129 | 149 | 192 | 210 |
| 6 | 77.0 | 97.1 | 125 | 146 | 187 | 206 |
| 8 | 75.2 | 96.5 | 124 | 144 | 186 | 204 |
| 10 | 73.8 | 94.9 | 122 | 142 | 184 | 203 |

Values of $1/E^*$ for loads of:

| Twist T.P.I. | 120 g. | 225 g. | 350 g. | 450 g. | 675 g. | 800 g. |
|---|---|---|---|---|---|---|
| 2 | 0.0125 | 0.0099 | 0.0078 | 0.0066 | 0.0052 | 0.0047 |
| 4 | 0.0125 | 0.0099 | 0.0078 | 0.0067 | 0.0052 | 0.0048 |
| 6 | 0.0130 | 0.0103 | 0.0080 | 0.0069 | 0.0053 | 0.0049 |
| 8 | 0.0133 | 0.0104 | 0.0080 | 0.0070 | 0.0054 | 0.0049 |
| 10 | 0.0136 | 0.0105 | 0.0082 | 0.0070 | 0.0054 | 0.0049 |

NOTE: Each value is an average of 15 determinations.
* $E$ = modulus of elasticity in grams per denier.

The pulse propagation meter, as previously indicated, when employed in conjunction with laboratory tensile-testing equipment, yields an autographic plot on rectangular coordinates of time in micro-seconds versus elapsed testing time. The speed of the chart of the recorder can be related to the rate of application of load or deformation, and hence the elapsed-time axis is a representation of load or extension depending upon whether testing is carried out at constant rate of load or constant rate of deformation.

The speed of the recorder chart may be varied to yield any desirable extent of magnification of the load or deformation. Magnification of the micro-second coordinate is accomplished by a selection of crystal separation which yields the maximum pen displacement on the chart for the particular material under test. Two full-scale ranges are available—namely, 0 to 100 micro-seconds and 0 to 500 micro-seconds—in order to adequately accommodate materials covering a wide range of moduli of elasticity.

In order to make possible the evaluation of moduli of short lengths of specimen, such as single wool fibers or single cotton fibers, a delay mechanism has been incorporated into the instrument which produces a delay of approximately 25 micro-seconds. Since the rochelle salt crystals may also introduce an unknown delay in the propagation of the pulse through the specimen, it is necessary to determine the delay constant of the instrument. This is accomplished by measuring the time of propagation of compression waves produced in the material for various crystal spacings. Such a calibration curve is shown in Figure 10. It will be observed that the curve is linear. The intercept with the micro-second axis is identical for all materials tested. The intercept at the ordinate represents the delay of the system expressed in micro-seconds, and this delay must be subtracted from all chart readings when absolute values of propagation time are required.

Crystal specimen contact is a critical factor in the use of piezo-electric type of transducers, and despite the fact that calibration curves to determine mini-

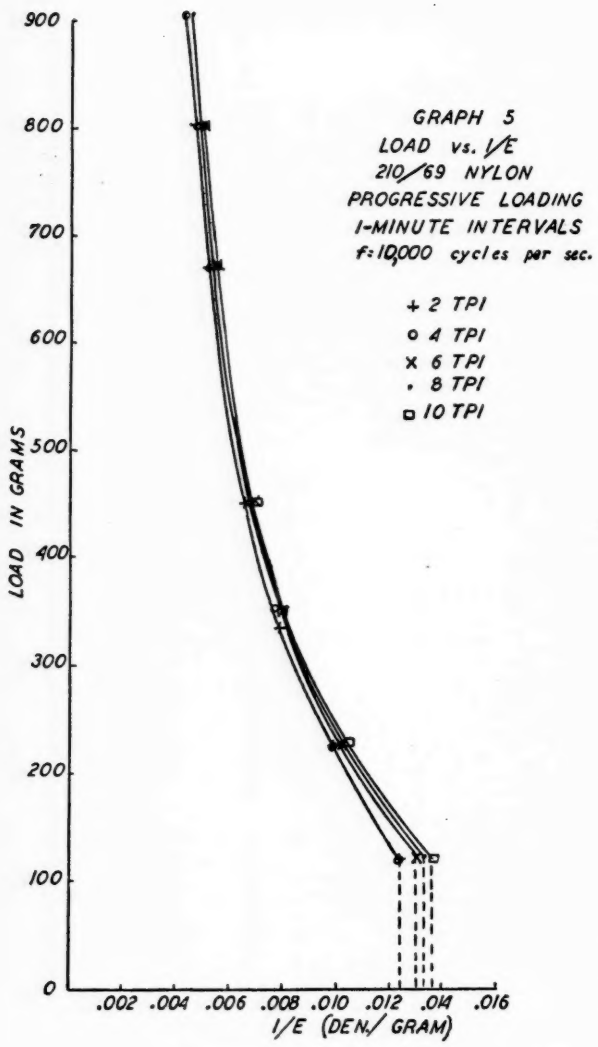
TABLE VI. PROGRESSIVE LOADING DATA FOR NYLON, TYPE 400, 34 FILAMENTS, 1 T.P.I.

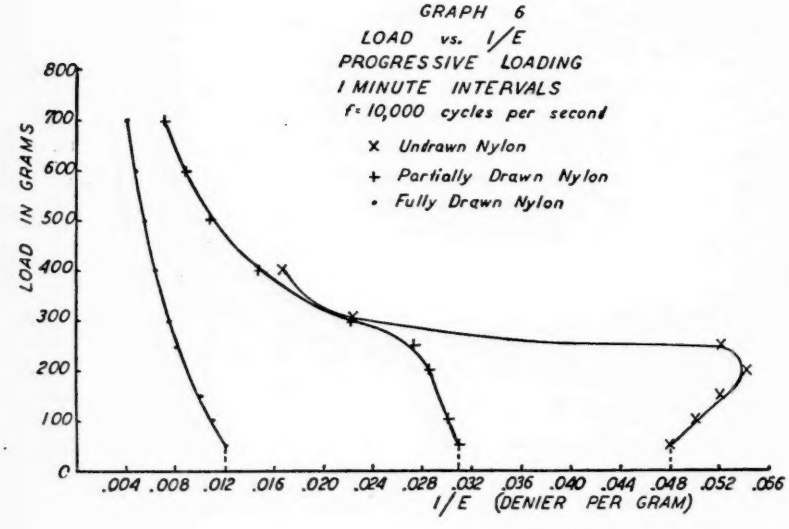
$f$ = 10,000 c.p.s. Input = 2.0 volts. 1-minute intervals.

| Degree of drawing | Values of E* for loads of: 50 g. | 100 g. | 150 g. | 200 g. | 250 g. | 300 g. | 400 g. | 500 g. | 600 g. | 700 g. | 800 g. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Undrawn (1,030 denier) | 20.8 | 20.0 | 19.1 | 18.4 | 19.2 | 45.3 | 60.3 | — | — | — | — |
| Partially drawn (550 denier) | 33.6 | 34.3 | — | 34.8 | 36.5 | 44.8 | 68.1 | 92.5 | 114 | 139 | — |
| Fully drawn (200 denier) | 83.1 | 90.3 | 98.6 | 107 | 124 | 135 | 160 | 185 | 208 | 230 | 245 |

| Degree of drawing | Values of 1/E* for loads of: 50 g. | 100 g. | 150 g. | 200 g. | 250 g. | 300 g. | 400 g. | 500 g. | 600 g. | 700 g. | 800 g. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Undrawn (1,030 denier) | 0.0480 | 0.0501 | 0.0522 | 0.0542 | 0.0521 | 0.0221 | 0.0166 | — | — | — | — |
| Partially drawn (550 denier) | 0.0298 | 0.0291 | — | 0.0287 | 0.0274 | 0.0223 | 0.0147 | 0.0108 | 0.0088 | 0.0072 | — |
| Fully drawn (200 denier) | 0.0120 | 0.0111 | 0.0101 | 0.0093 | 0.0081 | 0.0074 | 0.0063 | 0.0054 | 0.0048 | 0.0044 | 0.0041 |

NOTE: Each value is an average of 20 determinations.
* E = modulus of elasticity in grams per denier.




independent of load up to the yield point. The higher-twist yarns showed a constant modulus for only a negligible load variation.

The immediate elastic deflections of each of these filamentous yarns are depicted on Graph 8a. The curves indicate a similarity of shape and displacements along the deflection axis corresponding to variations in the modulus values: that is, *lower* immediate elastic deflections correspond to *higher* values of moduli.

The quantity $P/A$ (see pages 710 and 711) was calculated, compensating for both differences in initial denier with twist and changes in denier resulting from extensions caused by load application.

Results for the staple acetate yarns of various twists are presented in Table IX and represented on Graphs 9a and 9b. Examination of these graphs and comparison with Graph 8 indicate the following:

1. Independent of staple length, the higher the twist, the lower the sonic modulus.

2. At approximately the same twists (23–24 t.p.i.), the staple-fiber yarn shows a lower modulus than the continuous-filament yarn.

3. At corresponding twists, the $1\frac{1}{2}$-inch staple yarn shows a lower modulus than the $2\frac{1}{2}$-inch staple.

The immediate elastic deflections of the various twists for both staple lengths are shown on Graphs 9c and 9d. As was the case for the filamentous yarns, *lower* immediate elastic deflections are manifested by yarn constructions yielding *higher* moduli of elasticity.

*Part 3. Pulse-Propagation Procedure*

*Materials Investigated*

Tennessee Eastman Acetate Rayon
300 denier, 104 filaments, containing 1.5 turns per inch of twist

American Viscose Rayon
150 denier, 40 filaments, containing 3 turns per inch of twist

DuPont Nylon Type 300
60 denier, 20 filaments, containing 1 turn per inch of twist.

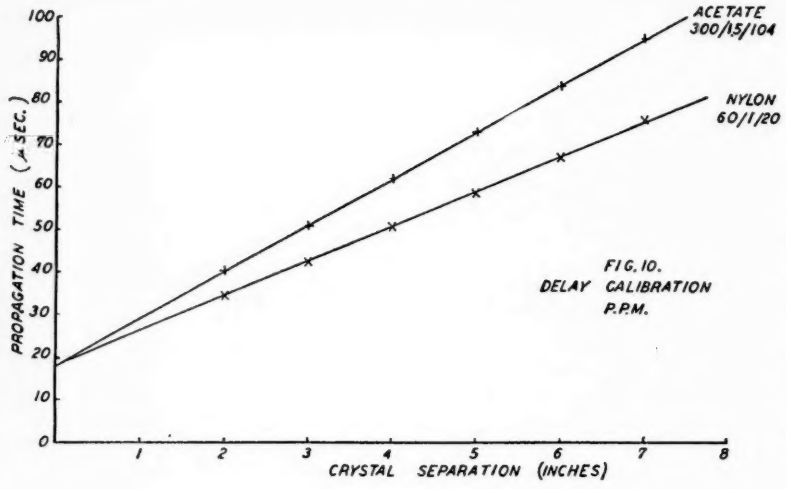



FIG. 10.
DELAY CALIBRATION P.P.M.

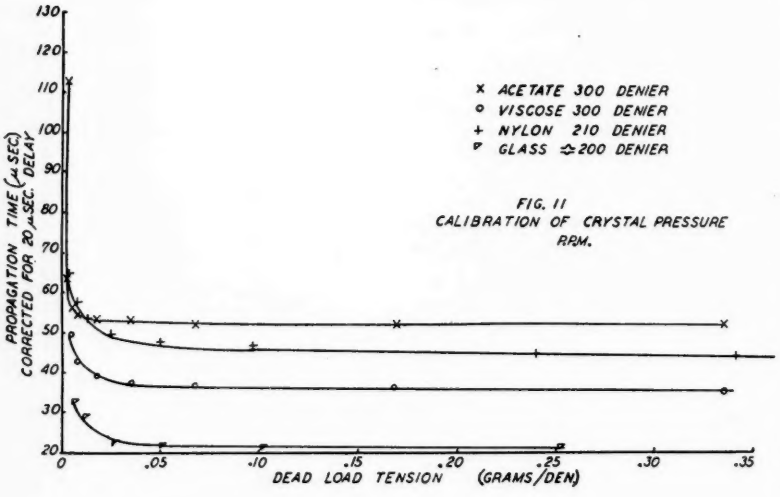

× ACETATE 300 DENIER
○ VISCOSE 300 DENIER
+ NYLON 210 DENIER
▽ GLASS ≈200 DENIER
PROPAGATION TIME (μ SEC.) CORRECTED FOR 20 μ SEC. DELAY
DEAD LOAD TENSION (GRAMS/DEN)

FIG. 11
CALIBRATION OF CRYSTAL PRESSURE R.P.M.

mum stable crystal loads have been constructed, a question still arises as to whether the initial curvature of the $1/E$ versus stress diagrams for the acetate and viscose is indicative of the properties of the material or whether it may be attributed solely to a "violin bow" effect created by the specimen being drawn across the crystal as extension takes place. The fact that nylon does not exhibit the same peculiar initial curvature further beclouds the issue. Subsequent studies will, it is hoped, throw further light on this phase of the research.

Calibration curves of crystal pressure versus constancy-of-time values have been constructed for acetate rayon, viscose rayon, nylon, and glass, and are shown in Figure 11.

From the curves it is apparent that an initial crystal loading of 0.1 gram per denier results in a stable time value. It should be pointed out, however, that these curves were obtained by the application of a static load, and that the experimental results yield the peculiar initial curvature on the micro-second versus elapsed-time chart as produced by the instrument, despite the application of the initial crystal loading of 0.1 gram per denier. This seems to point to the fact that the "violin bow" action is probably responsible for the curve distortion, and it is assumed in this research that the distortion is an artifact attributable to some crystal-specimen friction effect.

The data herein presented were obtained by using a crystal separation of 7 inches, since such a path length produced a chart of the most desirable dimensions. The testing-machine jaw separation ranged from 10.75 inches to 15 inches, and strains were calculated accordingly.

Results of tests on acetate, viscose, and nylon subjected to rupture loads are indicated in Table X and plotted as $1/E$ versus stress in grams per denier (Graph 10). Further tests were conducted on these materials subjected to repeated stress at loads below rupture, and the results thereof are indicated in Tables XI, XII, and XIII for acetate, viscose, and nylon, respectively. The data are plotted as $1/E$ versus stress in grams per denier. Graphs 11, 12, and 13 depict the curves for acetate, viscose, and nylon.

Immediate elastic deflections for three materials are plotted in Graphs 11a, 12a, and 13a for acetate, viscose, and nylon, in that order.

A review of the results obtained by the three procedures as outlined at the commencement of this section reveals the following:

1. Continuous-loading procedures (2) and (3) yield higher values of moduli than does the dead-loading procedure. This is quite understandable since faster rates of loading prevail in the continuous-loading procedures, and increases in moduli occur with increases in rates of load or strain application.

2. Reproducibility of results obtained from the three procedures is extremely high.

3. Although the results of the semi-autographic

TABLE VII. MODULUS OF ELASTICITY FROM PROGRESSIVE LOADING PROCEDURE FOR ACETATE, VISCOSE, AND NYLON

$f$ = 10,000 c.p.s. Input = 2 volts. 1-minute intervals.

Values of E* for loads of:

| Material | 25 g. | 50 g. | 75 g. | 100 g. | 125 g. | 150 g. | 175 g. | 200 g. | 225 g. | 250 g. |
|---|---|---|---|---|---|---|---|---|---|---|
| Acetate 150/3/40 | 54.2 | 54.9 | 54.9 | 61.8 | 89.5 | — | — | — | — | — |
| Viscose 150/3/40 | — | 127 | 127 | 130 | 143 | 147 | 158 | 166 | 176 | — |
| Unshrunk nylon 60/1/20 | — | 91.6 | 107 | 126 | 145 | 158 | 175 | 188 | 201 | 215 |
| Shrunk nylon 60/1/20 | — | 74.8 | 89.3 | 106 | 124 | 141 | 159 | 174 | 191 | 200 |

Values of 1/E* for loads of:

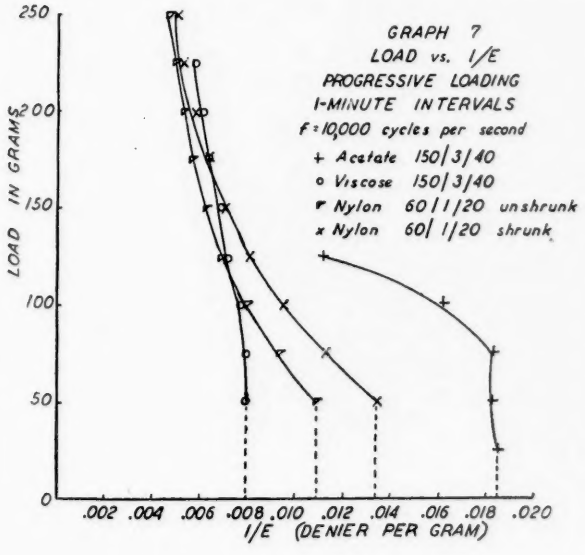
| Material | 25 g. | 50 g. | 75 g. | 100 g. | 125 g. | 150 g. | 175 g. | 200 g. | 225 g. | 250 g. |
|---|---|---|---|---|---|---|---|---|---|---|
| Acetate 150/3/40 | 0.0185 | 0.0182 | 0.0183 | 0.0162 | 0.0112 | — | — | — | — | — |
| Viscose 150/3/40 | — | 0.0079 | 0.0079 | 0.0077 | 0.0070 | 0.0068 | 0.0063 | 0.0060 | 0.0057 | — |
| Unshrunk nylon 60/1/20 | — | 0.0109 | 0.0093 | 0.0079 | 0.0069 | 0.0063 | 0.0057 | 0.0053 | 0.0050 | 0.0047 |
| Shrunk nylon 60/1/20 | — | 0.0134 | 0.0112 | 0.0095 | 0.0081 | 0.0071 | 0.0063 | 0.0057 | 0.0052 | 0.0050 |

NOTE: Each value for acetate is an average of 25 determinations. Each value for viscose is an average of 15 determinations. Each value for nylon is an average of 20 determinations.

* E = Modulus of elasticity in grams per denier.

procedure are satisfactory from the standpoint of reproducibility, it is evident that for higher values of applied loads or strains consistently low values of moduli are obtained. This is attributable to the occurrence of phase shifts resulting from the effects of unsatisfactory crystal response at the higher frequencies.

From the data presented, it becomes evident that the sonic moduli values obtained by any of the procedures are much more precise than are values for the more commonly measured textile properties; and, as will be evidenced in the next section, the need for more highly refined tensile-testing equipment to be used in conjunction with any type of sonic apparatus is definitely indicated.

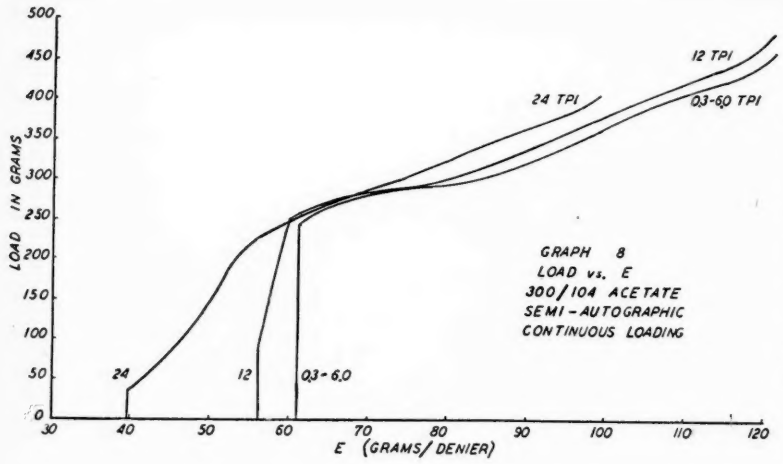



The pulse-propagation procedure lends itself most satisfactorily to the study of the analyses of stress-strain phenomena because of its speed and simplicity of operation as well as its important features of self-calibration and high precision. As a result, the analytical data presented in this work were all obtained with the use of the pulse propagation meter and are believed to be highly reliable in every respect.

### Analysis of Stress-Strain Curves

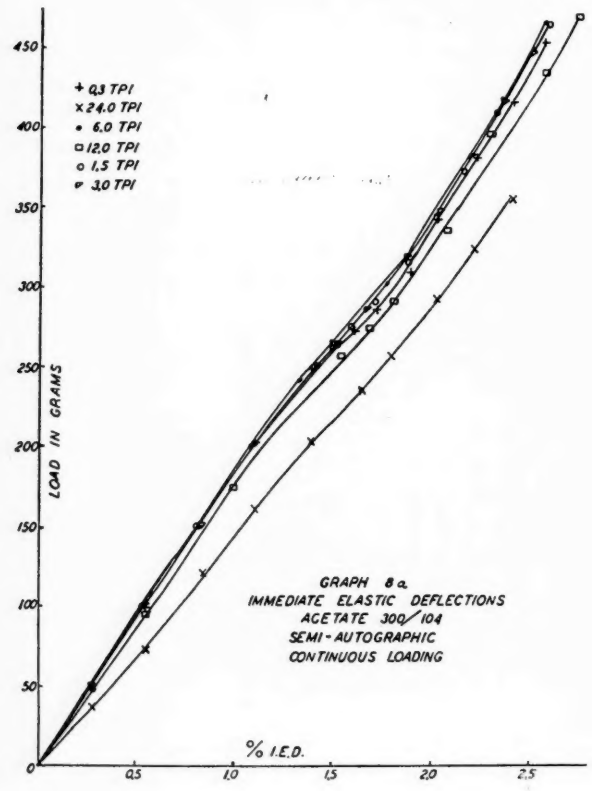
In the analysis of stress-strain curves of acetate, viscose, and nylon presented in this section, the Scott I-P-2 constant-rate-of-load, incline-plane tensile testing machine was employed. All tests were conducted at the 500-gram capacity, resulting in a rate of loading of 8.33 grams per second. The specimens were allowed to attain moisture-regain equilibrium with and were tested in a standard atmosphere of 70°F and 65 percent relative humidity.

As indicated in a previous section, any total load-strain curve can be analyzed for its three deflection




components—namely, immediate elastic deflection, primary creep deflection, and secondary creep deflection. The immediate elastic deflections of the materials under consideration were obtained from areas under their stress versus $1/E$ curves as described on pages 710 and 711.

The values of secondary creep in the first loading cycle were obtained by loading the specimen to a given percent of its ultimate load and then, by means of returning the carriage of the I-P-2 machine to its no-load position, immediately removing the load and maintaining the specimen in the unloaded slack condition until the unloading cycle of the machine operation was concluded. One minute was allowed to elapse before the secondary creep was measured. The minute interval was introduced to allow for primary creep recovery in order to assure separation of the two creep components. It is of course recognized that primary creep undoubtedly did not completely recover, but sufficient recovery took place for the specimen to evidence no further major retraction after the 1-minute interval.




Graph 10a is an analysis plot of the total load-strain curve of acetate 300/1.5/104, to rupture. The data for the total load-strain curve are given in Table XXXI. Immediate elastic deflections were calculated from Graph 10 in the prescribed manner. The secondary creep deflections above the yield point, observed from the procedure described above, are tabulated below:

| Load in Grams | % II Creep |
|---|---|
| 291 | 4.9 |
| 315 | 7.5 |
| 342 | 10.5 |
| 375 | 12.8 |
| 442 | 16.7 |

Values of secondary creep up to the yield point (constant-modulus range) were found to be zero. The I-P-2 load-extension diagrams for acetate revealed no permanent set resulting from repeated loading up to the yield point, the range in which a constant modulus was observed.

By subtracting the values of percent secondary creep, at their corresponding load values, from the total deflection curve, a curve representing the remaining deflection components is obtained. Up to the yield point, this curve represents the sum of the immediate elastic deflection and the primary creep deflection. Above the yield point, it represents the sum of the immediate elastic deflection and the primary creep deflection *plus* a residue of secondary creep deflection, the existence of which is due to the fact that it is not possible to remove all the secondary creep in one loading operation.

This curve of remaining deflection components represents the recoverable deformations resulting from one-time loading to rupture. These deforma-

TABLE VIII. LOAD-COMPLIANCE DATA FROM SEMI-AUTOGRAPHIC PROCEDURE FOR 300/104 ACETATE OF VARIOUS TWISTS

| 0.3 T.P.I. | | 1.5 T.P.I. | | 3 T.P.I. | | 6 T.P.I. | | 12 T.P.I. | | 24 T.P.I. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E |
| 50 | 0.0164 | 50 | 0.0162 | 50 | 0.0163 | 50 | 0.0166 | 50 | 0.0176 | 37 | 0.0251 |
| 100 | 0.0164 | 100 | 0.0162 | 100 | 0.0163 | 100 | 0.0166 | 95 | 0.0176 | 56 | 0.0239 |
| 150 | 0.0164 | 150 | 0.0162 | 150 | 0.0163 | 150 | 0.0166 | 174 | 0.0173 | 72 | 0.0227 |
| 200 | 0.0164 | 200 | 0.0162 | 200 | 0.0163 | 200 | 0.0166 | 255 | 0.0166 | 90 | 0.0217 |
| 246 | 0.0164 | 250 | 0.0162 | 246 | 0.0163 | 240 | 0.0166 | 266 | 0.0159 | 120 | 0.0207 |
| 263 | 0.0159 | 261 | 0.0162 | 254 | 0.0159 | 266 | 0.0159 | 273 | 0.0153 | 161 | 0.0197 |
| 272 | 0.0153 | 265 | 0.0159 | 263 | 0.0153 | 273 | 0.0153 | 289 | 0.0139 | 203 | 0.0189 |
| 285 | 0.0139 | 274 | 0.0153 | 285 | 0.0139 | 288 | 0.0139 | 307 | 0.0126 | 220 | 0.0181 |
| 296 | 0.0126 | 289 | 0.0139 | 298 | 0.0126 | 301 | 0.0126 | 334 | 0.0116 | 235 | 0.0173 |
| 313 | 0.0116 | 300 | 0.0126 | 318 | 0.0116 | 329 | 0.0116 | 359 | 0.0106 | 246 | 0.0166 |
| 342 | 0.0106 | 315 | 0.0116 | 346 | 0.0106 | 345 | 0.0106 | 395 | 0.0098 | 255 | 0.0159 |
| 381 | 0.0098 | 337 | 0.0106 | 381 | 0.0098 | 379 | 0.0098 | 432 | 0.0090 | 268 | 0.0153 |
| 420 | 0.0090 | 372 | 0.0098 | 415 | 0.0090 | 418 | 0.0090 | 468 | 0.0084 | 292 | 0.0139 |
| 452 | 0.0084 | 409 | 0.0090 | 446 | 0.0084 | 449 | 0.0084 | 487 | 0.0083 | 322 | 0.0126 |
| | | 450 | 0.0084 | 459 | 0.0082 | 465 | 0.0083 | | | 355 | 0.0116 |
| | | 463 | 0.0083 | | | | | | | 382 | 0.0106 |
| | | | | | | | | | | 407 | 0.0101 |

NOTE: Each value is an average of 12 determinations.

tions, although recoverable, are not elastic, since a portion of secondary creep is still potential in the specimen. If the specimen could be reloaded, the curve of recoverable deformations for the second cycle would not be of the same shape, since more, if not all, of the residual secondary creep would be removed by the repeated loading, leaving only immediate elastic and primary creep deflections to govern its limiting characteristics.

From the foregoing, it is at once evident that an analysis of a one-time-loading-to-rupture diagram made in the manner described above does not yield sufficient information from which to predict the performance of the material in repeated stress without the consideration of certain concepts to be discussed later in this paper.

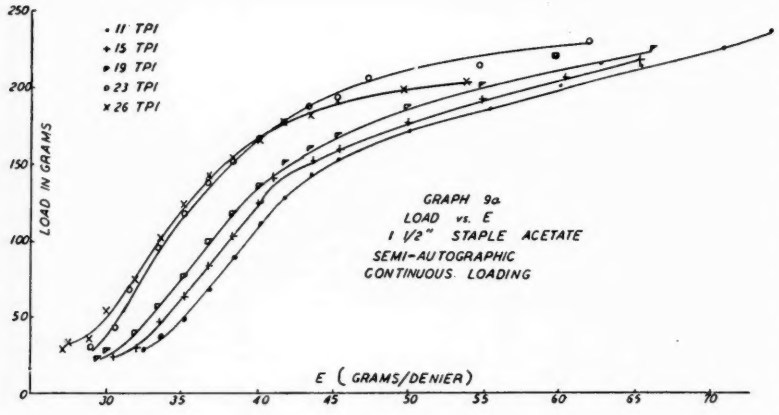
Graph 10b shows the total load-strain curve for viscose 150/3/40, the data for which will be found in Table XXXI. The analytical procedure is the same as that followed for acetate, and the same conclusions relative to the secondary creep residue apply in the case of viscose.

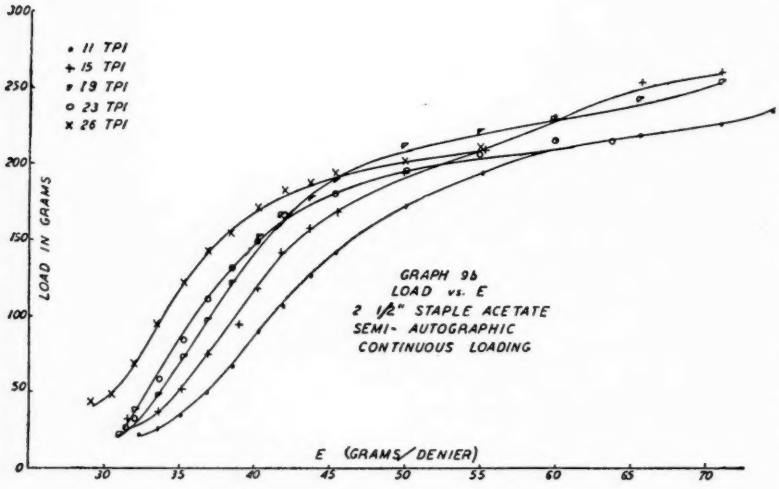
The secondary creep deflections for viscose are tabulated below:

| Load in Grams | % II Creep |
|---|---|
| 65 | 0 |
| 115 | 0 |
| 165 | 1.90 |
| 215 | 3.81 |
| 265 | 5.43 |
| 315 | 8.11 |

Graph 10c represents the analysis of the total load-strain curve for nylon 60/1/20. The data for the *total* curve appear in Table XXXI. There is no constant modulus region as there is for acetate or viscose. However, the original modulus is reproducible upon repeated loading to all loads, including those at which the specimen approaches rupture. The magnitude of secondary creep is extremely low, and its removal does not appear to affect the modulus. The primary creep, however, has a major effect, causing major increases in modulus with increases in load. The modulus decreases, correspondingly, with decreases in load and attains its original value after completion of the loading and unloading cycles. Therefore, the one-time-loading-to-rupture analysis for nylon results in a curve of remaining deflection components which is essentially that of the total stress-strain curve, and repeated stress performance may be adequately predicted from the one-time-loading-to-rupture curve without recourse to additional analytical procedures.

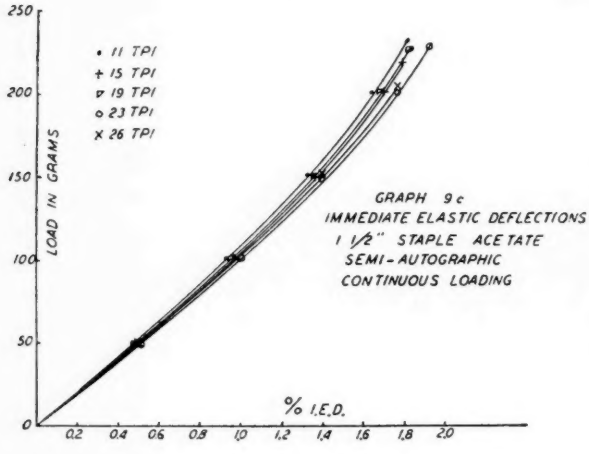
It may be postulated that for given constant ambient conditions of temperature and humidity, a particular material possesses a maximum potential ability to exhibit each of its three deflection components, either separately or in combination. The removal or alteration of any one of these components may result in the manifestation of changes in the others. Repeated-stress diagrams for acetate and viscose from autographic tensile-testing machines reveal interesting facts—namely, that, starting with the first




loading diagram below the yield point, a series of *repeated* loading diagrams resulting from the application of successively higher loads are related in such a manner that the path of the conditioned cycle curve resulting from an additional load increment is a continuation of the conditioned cycle curve resulting from the next preceding load. If the displaced curves representing a selected series of loads from zero to a load approaching that at which rupture would occur are superposed upon each other from a common origin, a curve will be obtained which is the locus of points representing the sum of the immediate elastic deflection and the primary creep deflection, since secondary creep is completely removed, for all practical purposes, at the conditioned cycle. These facts indicate that regardless of the load to which the material is subjected for its mechanical conditioning, the *sum* of the immediate elastic deflection and the primary creep deflection for any load equal to or less than the conditioning load is constant for all loading cycles.

The shift of the conditioned-cycle loading curve along the deflection axis is a function of the extent of secondary creep removal. It has been observed that a parabolic relationship exists between removal of secondary creep and modulus of elasticity for materials exhibiting a definite flow region and high magnitudes of secondary creep. The removal of secondary creep, although it shifts



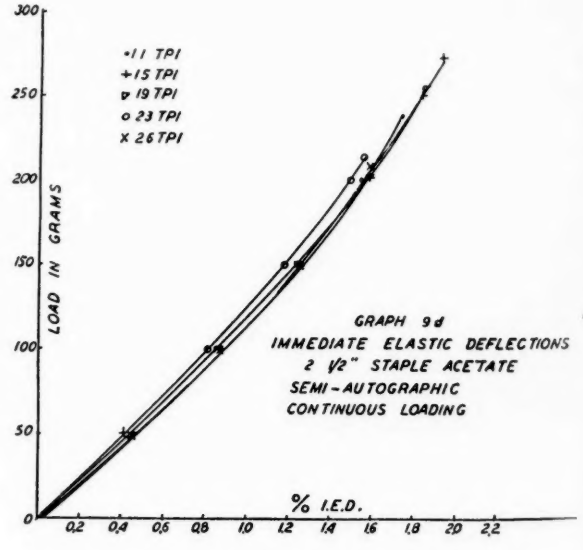



TABLE IX. LOAD-COMPLIANCE DATA FROM SEMI-AUTOGRAPHIC PROCEDURE FOR STAPLE ACETATE

| 1½-inch staple | | | | | | | | | | | | 2½-inch staple | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 T.P.I. | | 15 T.P.I. | | 19 T.P.I. | | 23 T.P.I. | | 26 T.P.I. | | 11 T.P.I. | | 15 T.P.I. | | 19 T.P.I. | | 23 T.P.I. | | 26 T.P.I. | |
| Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E | Load (g.) | 1/E |
| 31 | 0.0310 | 25 | 0.0327 | 23 | 0.0338 | 31 | 0.0345 | 31 | 0.0367 | 21 | 0.0310 | 32 | 0.0316 | 21 | 0.0322 | 25 | 0.0318 | 42 | 0.0342 |
| 36 | 0.0298 | 31 | 0.0312 | 28 | 0.0327 | 43 | 0.0327 | 32 | 0.0362 | 25 | 0.0297 | 30 | 0.0312 | 38 | 0.0312 | 32 | 0.0312 | 47 | 0.0327 |
| 49 | 0.0284 | 47 | 0.0298 | 40 | 0.0312 | 68 | 0.0312 | 36 | 0.0344 | 34 | 0.0284 | 36 | 0.0298 | 47 | 0.0298 | 57 | 0.0298 | 68 | 0.0312 |
| 68 | 0.0272 | 64 | 0.0284 | 57 | 0.0298 | 95 | 0.0298 | 55 | 0.0327 | 49 | 0.0272 | 51 | 0.0284 | 72 | 0.0284 | 83 | 0.0284 | 93 | 0.0298 |
| 88 | 0.0260 | 84 | 0.0272 | 77 | 0.0284 | 116 | 0.0284 | 74 | 0.0312 | 66 | 0.0260 | 74 | 0.0272 | 95 | 0.0272 | 110 | 0.0272 | 119 | 0.0284 |
| 114 | 0.0249 | 103 | 0.0260 | 99 | 0.0272 | 137 | 0.0272 | 102 | 0.0298 | 89 | 0.0249 | 93 | 0.0260 | 121 | 0.0260 | 129 | 0.0260 | 140 | 0.0272 |
| 128 | 0.0239 | 124 | 0.0249 | 118 | 0.0260 | 151 | 0.0260 | 123 | 0.0284 | 106 | 0.0239 | 117 | 0.0249 | 148 | 0.0249 | 148 | 0.0249 | 153 | 0.0260 |
| 142 | 0.0229 | 139 | 0.0239 | 136 | 0.0249 | 164 | 0.0249 | 140 | 0.0272 | 125 | 0.0229 | 140 | 0.0239 | 165 | 0.0239 | 165 | 0.0239 | 167 | 0.0249 |
| 153 | 0.0220 | 152 | 0.0229 | 151 | 0.0239 | 176 | 0.0239 | 153 | 0.0260 | 140 | 0.0220 | 157 | 0.0229 | 178 | 0.0229 | 176 | 0.0229 | 180 | 0.0239 |
| 170 | 0.0200 | 160 | 0.0220 | 160 | 0.0229 | 185 | 0.0229 | 166 | 0.0249 | 172 | 0.0200 | 167 | 0.0220 | 189 | 0.0220 | 180 | 0.0220 | 187 | 0.0229 |
| 184 | 0.0182 | 176 | 0.0200 | 168 | 0.0220 | 192 | 0.0220 | 175 | 0.0239 | 193 | 0.0182 | 193 | 0.0200 | 212 | 0.0200 | 195 | 0.0200 | 193 | 0.0220 |
| 201 | 0.0166 | 192 | 0.0182 | 186 | 0.0200 | 206 | 0.0200 | 180 | 0.0229 | 214 | 0.0166 | 210 | 0.0182 | 223 | 0.0182 | 206 | 0.0182 | 201 | 0.0200 |
| 213 | 0.0153 | 206 | 0.0166 | 202 | 0.0182 | 214 | 0.0182 | 191 | 0.0220 | 220 | 0.0153 | 281 | 0.0166 | 229 | 0.0166 | 214 | 0.0166 | 208 | 0.0182 |
| 224 | 0.0141 | 218 | 0.0153 | 220 | 0.0166 | 222 | 0.0166 | 197 | 0.0200 | 227 | 0.0141 | 252 | 0.0153 | 242 | 0.0153 | 224 | 0.0157 | — | — |
| 235 | 0.0135 | — | — | 226 | 0.0151 | 229 | 0.0161 | 204 | 0.0185 | 237 | 0.0134 | 259 | 0.0141 | 254 | 0.0141 | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | 273 | 0.0132 | — | — | — | — | — | — |

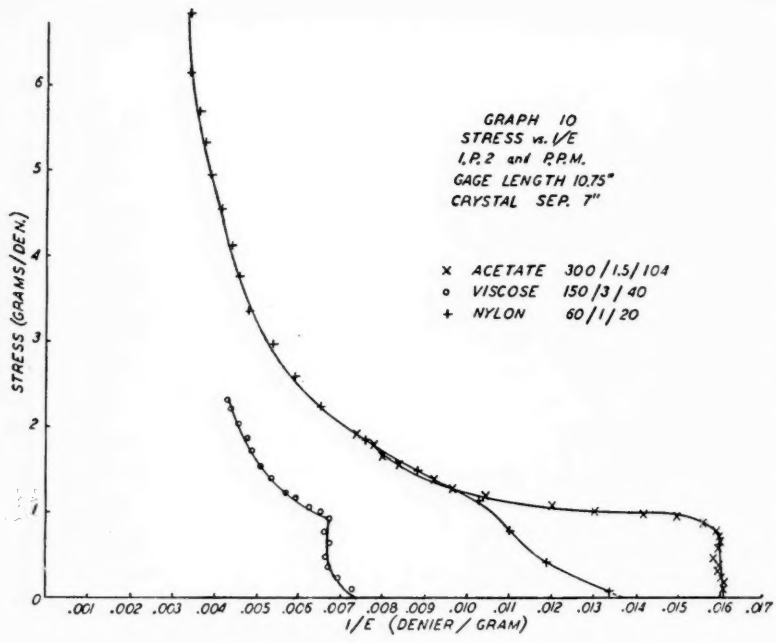
NOTE: Each value is an average of 25 determinations.

the curves from the origin, does not affect the constant values of the sums of the immediate elastic and primary creep deflections.

Thus, the removal of one component—namely, secondary creep—has resulted in the manifestation of constant sums of the other two components, which sums appear to represent the maximum potential value of these two in interaction.

The fact that the sum of these two components remains constant at a limiting value at any load equal to or less than the conditioning load for all loading cycles regardless of the conditioning load justifies the use of conditioned-cycle deflection values, plotted from the first cycle origin, as the curve depicting the sum of immediate elastic and primary creep deflections in the analysis of the first-cycle total load-strain curve. It should be pointed out that the immediate elastic deflection as determined by the sonic technique represents the sum of a series of deflection increments which result from minute deformation produced in the specimen as the result of the propagation of the sonic pulse. These deflection increments are independent of the specimen length as defined by the initial separation of the jaws of the tensile testing machine (gage length). The immediate elastic deflection may, therefore, be expressed as a percent of the original gage length or any other selected specimen length. Since the values of the sums of the immediate elastic and primary creep deflections are constant for all conditioning loads even though each successive load increase creates an additional length of specimen, it, too, may be expressed as a percentage of the original or any other selected gage length. Secondary creep is orthodoxly expressed as a percent of the original specimen length. Thus, all deflection components of the total one-time-loading-to-rupture curve may be expressed as percents of the original gage length, thereby providing a uniform base for comparison of deflections.

The analysis of total load-strain curves discussed so far was based upon data taken on the three materials, acetate, viscose, and nylon, for one-time loading to rupture. These three materials were further studied on a repeated stress basis for the purpose of more critically analyzing the deflection components. Graph 11b depicts the total load-strain curve, together with the deflection components obtained. Comparison of Graph 11b with Graph 10a reveals the addition of two curves—namely, the immediate elastic deflection for the sixth loading cycle and the




immediate elastic deflection plus the primary creep curve obtained from the sixth loading cycle data as previously described.

It is believed that if this latter curve could be constructed for loads up to and including that required for rupture, it would terminate at a point which would be common to the curve of secondary creep residue plus immediate elastic deflection plus primary creep, if this curve were also constructed for loads up to and including that required for rupture. The difference in deflections between the two curves in the region from the yield point to rupture represents the magnitude of the secondary creep residue present at the end of the first loading cycle.

The immediate elastic deflection for the sixth loading cycle is considerably less than that for the first loading cycle. Since it has already been established that the sum of immediate elastic plus primary creep deflection at any load equal to or less than the conditioning load remains constant from the first cycle to the conditioned cycles, it becomes apparent that the immediate elastic deflection decreases and the primary creep deflection increases with mechanical conditioning.

A study of the stress versus $1/E$ curves for acetate under repeated stress application (Graph 11) reveals that the modulus of elasticity, when plotted versus stress, describes a hysteresis loop in the absence of secondary creep, as is indicated by the sixth loading and sixth unloading curves. Evidently, the effect of primary creep is to "cold work" the material in a delayed recoverable fashion, as compared to the delayed non-recoverable cold working resulting from second creep removal.

Graph 11a, depicting immediate elastic deflections and immediate elastic recoveries for the first and sixth cycles, indicates the existence of a hysteresis loop for the immediate elastic components at the conditioned cycle. The modulus ranges between a minimum and a maximum value, and the immediate elastic component does likewise. The removal of secondary creep has completely eliminated the constant modulus range between zero and the yield stress.

Graph 11c is a plot of the three deflection components of the total load-strain curve. It is of interest to note that the primary creep curve crosses the immediate elastic deflection curve of the

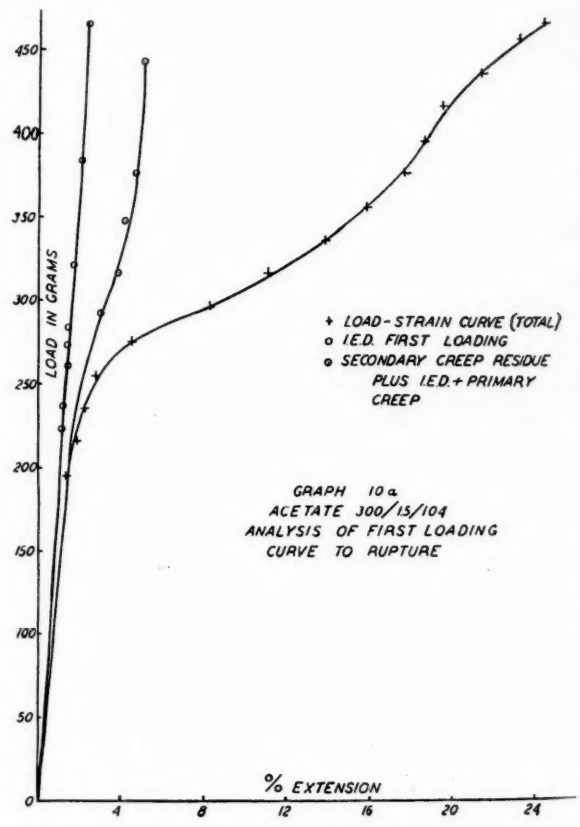


TABLE X. STRESS-COMPLIANCE DATA FROM PULSE-PROPAGATION PROCEDURE—LOADING TO RUPTURE

| Acetate 300/1.5/104 | | | | | Viscose 150/3/40 | | | | | Nylon 60/1/20 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *D* | *P* | *P/d* | *t* | 1/*E* | *D* | *P* | *P/d* | *t* | 1/*E* | *D* | *P* | *P/d* | *t* | 1/*E* |
| 0.0 | 35 | 0.116 | 76.2 | 0.0161 | 0.0 | 15 | 0.1 | 51.3 | 0.00730 | 0.0 | 5 | 0.083 | 69.0 | 0.0134 |
| 0.2 | 55 | 0.183 | 76.2 | 0.0161 | 0.2 | 35 | 0.233 | 50.0 | 0.00695 | 0.2 | 25 | 0.423 | 65.5 | 0.0119 |
| 0.4 | 75 | 0.250 | 76.0 | 0.0160 | 0.4 | 55 | 0.367 | 49.2 | 0.00674 | 0.4 | 45 | 0.770 | 63.0 | 0.0110 |
| 0.6 | 95 | 0.315 | 75.8 | 0.0159 | 0.6 | 75 | 0.500 | 49.0 | 0.00668 | 0.6 | 65 | 1.120 | 61.0 | 0.0103 |
| 0.8 | 115 | 0.383 | 76.0 | 0.0160 | 0.8 | 95 | 0.633 | 49.2 | 0.00674 | 0.8 | 85 | 1.48 | 56.2 | 0.00879 |
| 1.0 | 135 | 0.450 | 75.9 | 0.0159 | 1.0 | 115 | 0.717 | 49.0 | 0.00668 | 1.0 | 105 | 1.85 | 52.3 | 0.00763 |
| 1.2 | 155 | 0.516 | 76.0 | 0.0160 | 1.2 | 135 | 0.925 | 49.2 | 0.00674 | 1.2 | 125 | 2.22 | 48.5 | 0.00653 |
| 1.4 | 175 | 0.584 | 76 0 | 0.0160 | 1.3 | 145 | 1.00 | 48.5 | 0.00652 | 1.4 | 145 | 2.59 | 46.0 | 0.00589 |
| 1.6 | 195 | 0.659 | 76.0 | 0.0160 | 1.4 | 155 | 1.07 | 47.4 | 0.00625 | 1.6 | 165 | 2.96 | 44.0 | 0.00538 |
| 1.8 | 215 | 0.730 | 76.0 | 0.0160 | 1.5 | 165 | 1.16 | 46.4 | 0.00598 | 1.8 | 185 | 3.35 | 41.6 | 0.00481 |
| 2.0 | 235 | 0.800 | 75.6 | 0.0159 | 1.6 | 175 | 1.24 | 45.3 | 0.00570 | 2.0 | 205 | 3.74 | 40.5 | 0.00456 |
| 2.2 | 255 | 0.871 | 75.0 | 0.0156 | 1.8 | 195 | 1.39 | 44.0 | 0.00538 | 2.2 | 225 | 4.12 | 39.6 | 0.00436 |
| 2.4 | 275 | 0.967 | 71.6 | 0.0142 | 2.0 | 215 | 1.54 | 42.9 | 0.00511 | 2.4 | 245 | 4.54 | 38.8 | 0.00420 |
| 2.6 | 295 | 1.010 | 65.7 | 0.0120 | 2.2 | 235 | 1.72 | 42.0 | 0.00490 | 2.6 | 265 | 4.93 | 37.6 | 0.00392 |
| 2.8 | 315 | 1.17 | 61.5 | 0.0105 | 2.4 | 255 | 1.88 | 41.4 | 0.00476 | 2.8 | 285 | 5.31 | 37.0 | 0.00381 |
| 3.0 | 335 | 1.27 | 59.0 | 0.00967 | 2.6 | 275 | 2.05 | 40.6 | 0.00457 | 3.0 | 305 | 5.70 | 36.0 | 0.00361 |
| 3.2 | 355 | 1.37 | 57.5 | 0.00919 | 2.8 | 295 | 2.22 | 40.0 | 0.00445 | 3.2 | 325 | 6.16 | 35.1 | 0.00342 |
| 3.4 | 375 | 1.45 | 56.2 | 0.00876 | 2.9 | 305 | 2.31 | 39.7 | 0.00439 | 3.4 | 345 | 6.85 | 33.5 | 0.00316 |
| 3.6 | 395 | 1.56 | 55.0 | 0.00840 | | | | | | | | | | |
| 3.8 | 415 | 1.65 | 53.8 | 0.00804 | | | | | | | | | | |
| 4.0 | 435 | 1.77 | 52.9 | 0.00776 | | | | | | | | | | |
| 4.2 | 455 | 1.86 | 52.0 | 0.00751 | | | | | | | | | | |
| 4.3 | 465 | 1.93 | 51.6 | 0.00740 | | | | | | | | | | |

NOTE: *D* = chart inches. *P* = load (grams). *P/d* = stress (grams/denier). *t* = time ($\mu$ seconds). 1/*E* = compliance (inverse modulus) in denier/gram.

first loading cycle. For lower loads, the primary creep deflection is less than the immediate elastic, whereas for higher loads it exceeds the immediate elastic. The secondary creep curve (which originates at the origin) is similar in shape to the original load-strain curve.

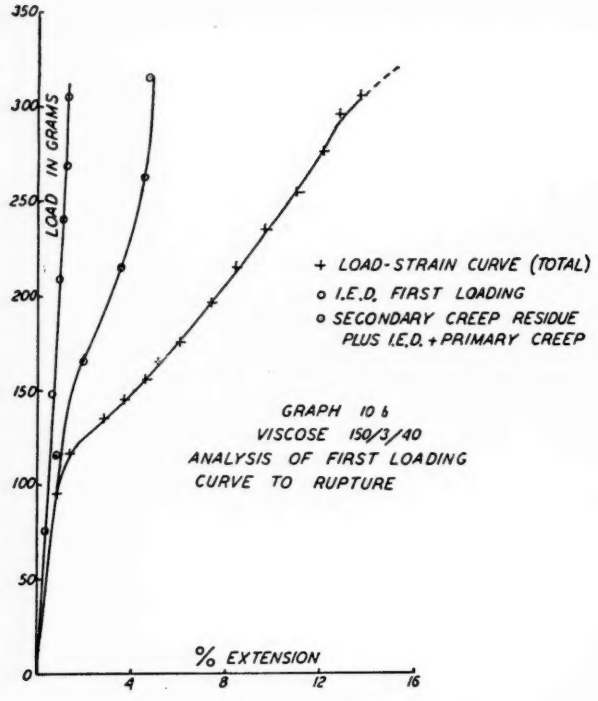
Graphs 11b and 11c clearly illustrate the small contribution which the *elastic* deflections make to the mechanical behavior of acetate rayon. Its poor dimensional stability and elastic performance both may be attributed to its low elastic-to-plastic ratio.

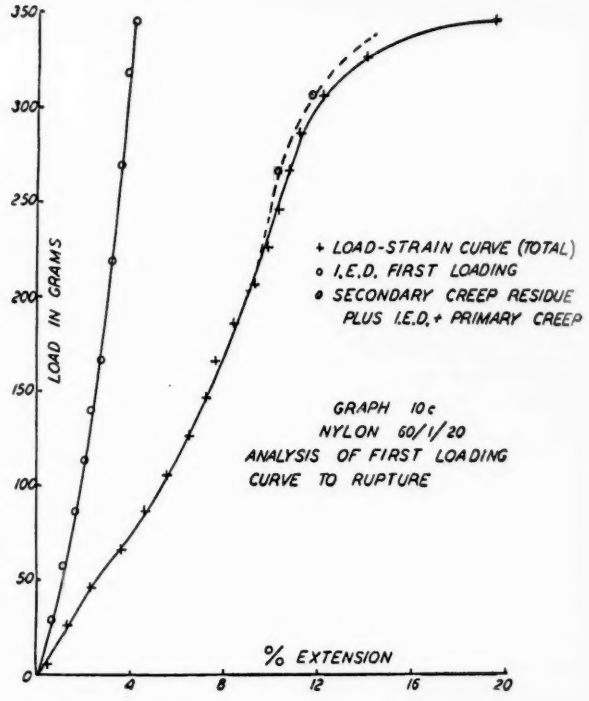
The analysis of the first loading curve of viscose is plotted on Graphs 12b and 12c. The stress versus 1/*E* and load versus immediate elastic deflections and recoveries are depicted on Graphs 12 and 12a. A study of these curves reveals that the performance of viscose is similar to that of acetate.

On Graphs 11, 11a, 12, and 12a, it will also be noted that the immediate elastic recovery for the first loading cycle very closely approximates that of the immediate elastic deflection of the conditioned cycle for both acetate and viscose. Also, the secants of the recovery curves for various conditioning loads above the yield point intersect the % I.E.D. (immediate elastic deflection) axis in such a manner that the residual deflections bear a logarithmic rela-

TABLE Xa. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE—LOADING TO RUPTURE

| Acetate 300/1.5/104 | | | Viscose 150/3/40 | | | Nylon 60/1/20 | | |
|---|---|---|---|---|---|---|---|---|
| Load (g.) | Stress (g./den.) | % I.E.D. | Load (g.) | Stress (g./den.) | % I.E.D. | Load (g.) | Stress (g./den.) | % I.E.D. |
| 222 | 0.75 | 1.20 | 37 | 0.25 | 0.17 | 30 | 0.50 | 0.64 |
| 235 | 0.80 | 1 28 | 75 | 0.50 | 0.33 | 57 | 1.00 | 1.17 |
| 260 | 0.90 | 1.44 | 113 | 0.75 | 0.49 | 85 | 1.50 | 1.66 |
| 272 | 0.95 | 1.51 | 145 | 1.00 | 0.66 | 115 | 2 00 | 2.05 |
| 282 | 1.00 | 1.58 | 177 | 1.25 | 0.82 | 140 | 2.50 | 2.38 |
| 320 | 1.20 | 1.81 | 208 | 1.50 | 0.94 | 167 | 3.00 | 2.66 |
| 365 | 1.50 | 2.09 | 240 | 1.75 | 1.08 | 217 | 4.00 | 3.16 |
| 465 | 1.93 | 2.42 | 268 | 2.00 | 1.19 | 270 | 5.00 | 3.56 |
| | | | 298 | 2.25 | 1.31 | 317 | 6.00 | 3.90 |
| | | | 305 | 2.31 | 1.32 | 345 | 6.55 | 4.19 |


LOAD IN GRAMS
% EXTENSION
+ LOAD-STRAIN CURVE (TOTAL)
o I.E.D. FIRST LOADING
o SECONDARY CREEP RESIDUE PLUS I.E.D. + PRIMARY CREEP
GRAPH 10 b
VISCOSE 150/3/40
ANALYSIS OF FIRST LOADING CURVE TO RUPTURE


LOAD IN GRAMS
% EXTENSION
+ LOAD-STRAIN CURVE (TOTAL)
o I.E.D. FIRST LOADING
o SECONDARY CREEP RESIDUE PLUS I.E.D. + PRIMARY CREEP
GRAPH 10 c
NYLON 60/1/20
ANALYSIS OF FIRST LOADING CURVE TO RUPTURE

tionship to their respective conditioning loads. There is no intercept for loads below the yield point.

The loading tests from which these data were obtained were performed as follows:

A specimen was loaded and unloaded once at each of a series of conditioning loads below and above the yield point. No time was allowed to elapse after the unloading, but, rather, the secondary creep deflection was taken to be the displacement from the origin of the end of the unloading curve. Sonic determinations were made simultaneously with the loading tests. Values of secondary creep so obtained evidenced a positive non-linear correlation with residual immediate elastic recoveries. Thus, it will be seen that a calculable relationship exists between load, residual recoveries, and secondary creep which when once determined for a given material permits the calculation of secondary creep from the residual immediate recoveries, and since the immediate elastic recovery curve obtained for the first unloading closely approximates the corresponding curves for the conditioned loading and unloading cycles, it is necessary to obtain data only from the first loading curves in analyzing for these two deflection components.

Reviewing the requirements for total load-strain curve analysis, the immediate elastic deflection is obtained from the first-cycle unloading curve. The immediate elastic plus the primary creep deflection curve is the conditioned-cycle loading curve. The secondary creep deflection may be calculated from the logarithmic relationship of the residual recovery deflections corresponding to various loads above the yield point, there being no manifestation of secondary creep for loads below the yield point for acetate and viscose; or it may be calculated by difference by subtracting the immediate elastic plus the primary creep deflections from the total deflection curve.

For nylon, an entirely different behavior is noted. From Graph 13, it will be observed that the first unloading causes the modulus to return almost to its original value, and that subsequent loading and unloading results in reproducible values of modulus at loads in the vicinity of the conditioning load. In the loading tests conducted on nylon in repeated stress, no time was allowed to elapse for primary creep recovery, and, hence, a superposition effect prevented both the loading and the recovery curves from reproducing themselves. The tensile load-deflection curves in repeated stress revealed a shift of the hysteresis loop from the origin along the deflection axis, as was the case for acetate and viscose, but the stress versus $1/E$ curve did not reflect a shift of similar trend or magnitude. The width of the

stress versus $1/E$ hysteresis loop was diminished, but the end-point values remained essentially the same for repeated cycles.

The immediate elastic deflections shown on Graph 13a reflect the load-deflection curve-hysteresis loop shift, but only as a result of a superposition effect created by the high magnitude of primary creep. If time were allowed for primary creep recovery, the agreement between immediate elastic deflections for first-cycle loading and unloading and conditioned-cycle loading and unloading would undoubtedly approach perfection.

Thus, it will be seen that the effect of primary creep in nylon for *all* cycles is similar to, but of greater magnitude than, that in acetate and viscose for the *conditioned* cycles. The "cold working" effect of primary creep of nylon is responsible for a hysteresis of the modulus, all increases in modulus due to loading being recoverable upon unloading.

Repeated stress diagrams for nylon, from autographic tensile-testing machines, reveal the facts that, starting with the first diagram for stresses of the order of 0.8 gram per denier, a series of repeated loading diagrams (allowing sufficient time between cycles for primary creep recovery), resulting from the application of successively higher loads, are related in such a manner that the end-point of the *conditioned*-cycle loading curve resulting from an additional load increment is a point on a curve representing the continuation of the *first*-cycle loading curve resulting from the next preceding load. If the end-points of the curves representing a selected series of loads from zero to a load approaching that required for rupture are superposed upon each other, a resultant curve will be obtained which is the locus of points representing the sum of the immediate elastic deflection and the primary creep deflection. These facts indicate that regardless of the load to which the material is subjected for its mechanical conditioning, the *sum* of the immediate elastic deflection and the primary creep deflection at any load equal to or less than the conditioning load is constant for all loading cycles.

Unlike the curves for acetate and viscose, the curve for nylon which depicts the locus of points of I.E.D. plus primary creep is the total load-strain curve resulting from the first loading cycle.

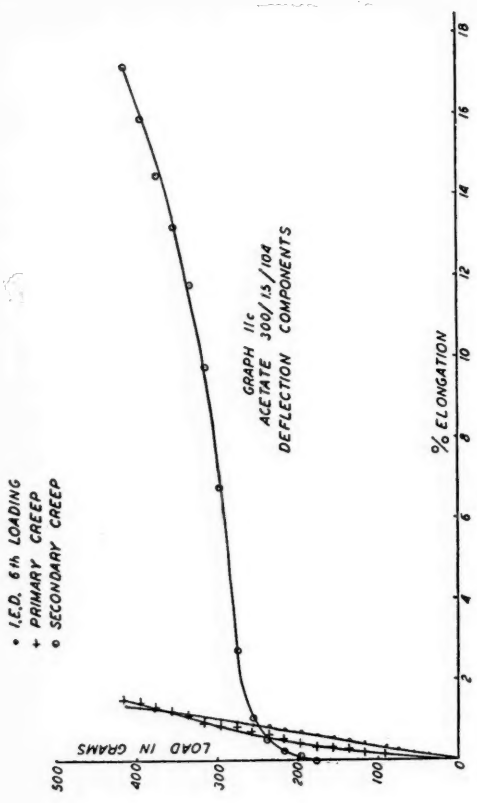
From the foregoing, it seems probable that what appears to be a secondary creep deflection at high loads is in reality a delay in recovery of the primary creep corresponding to that load. If such is the case, the total load-strain curve of the first loading cycle may be used as the curve of immediate elastic deflection plus primary creep. Hence, there will exist for nylon only two curves depicting deflection components of the total load-strain curve—namely, those of immediate elastic deflection and primary creep deflection.

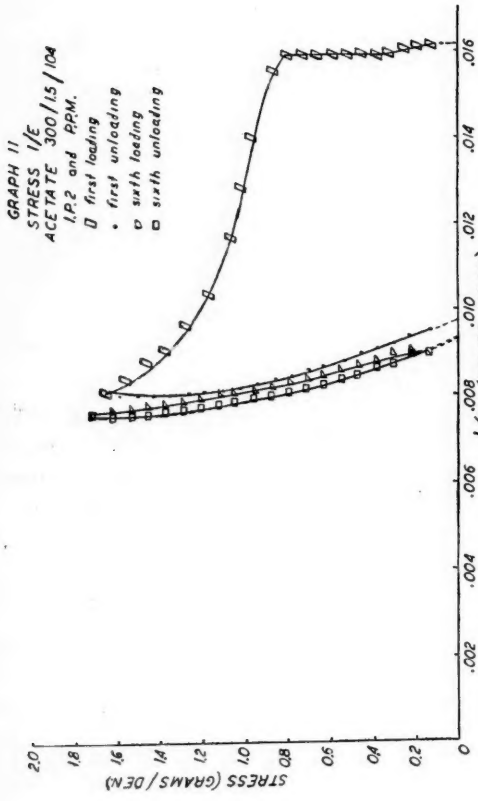
Graph 13b represents the analysis of the total load-strain curve. It will be noted that there is no separate curve indicating the sum of the immediate elastic and primary creep deflections. The immediate elastic deflection for the eighth cycle is considerably less than that for the first cycle only as the result of the superposition effect. As was the case for acetate and viscose, it is apparent that the decrease in immediate elastic deflection for the conditioned cycle is accompanied by a corresponding increase in primary creep deflection of a magnitude sufficient to maintain the sum of the two at a constant value. Graph 13c is a plot of the two deflection components of the total load-strain curve. As was the case for acetate and viscose, the primary creep curve crosses the immediate elastic deflection curve. The crossing takes place at a much lower percentage of ultimate load for nylon than for the other materials. Of particular interest is the fact that both these components are of much greater magnitude than the corresponding components for acetate and viscose. Furthermore, the primary creep, at the maximum load investigated under repeated stress, is in excess of one and one-half times the immediate elastic deflection.

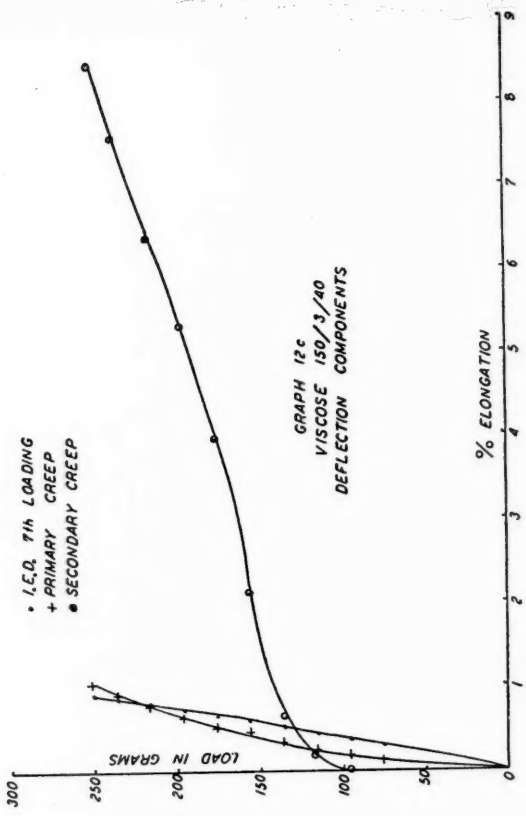
## Conclusions

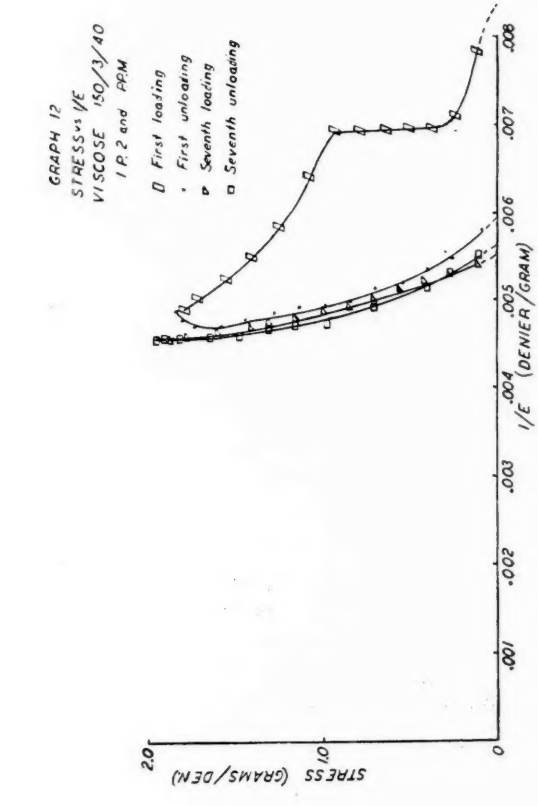
1. The three deflection components of a total load-strain curve—namely, immediate elastic deflection, primary creep deflection, and secondary creep deflection—can be quantitatively determined by the application of sonic techniques in conjunction with tensile testing techniques, for loads ranging from zero to the load required to rupture the specimen, under continuous-loading conditions.

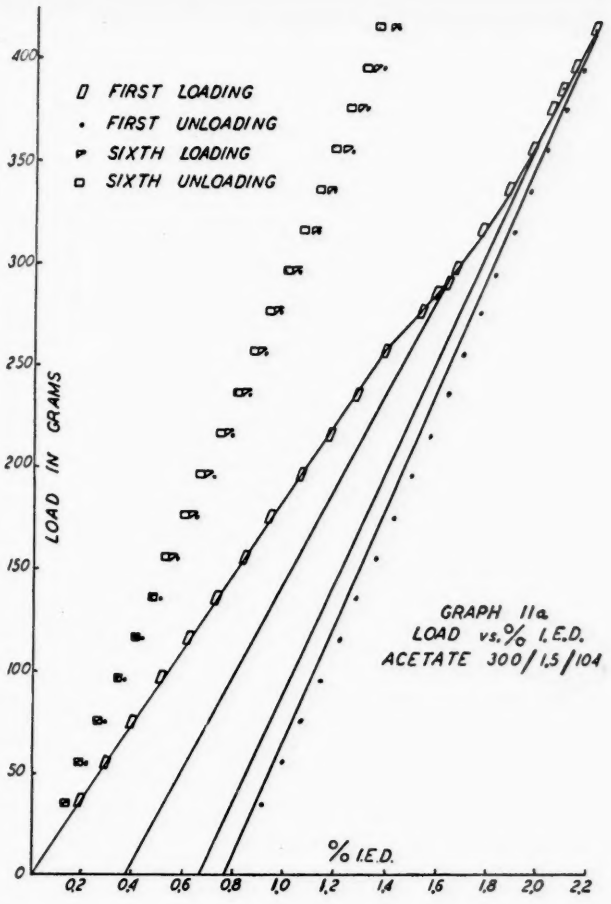
2. The techniques developed are applicable to tensile-testing procedures employing constant rates of load, elongation, or strain application, for different magnitudes of constant rates of load, elongation, or strain.

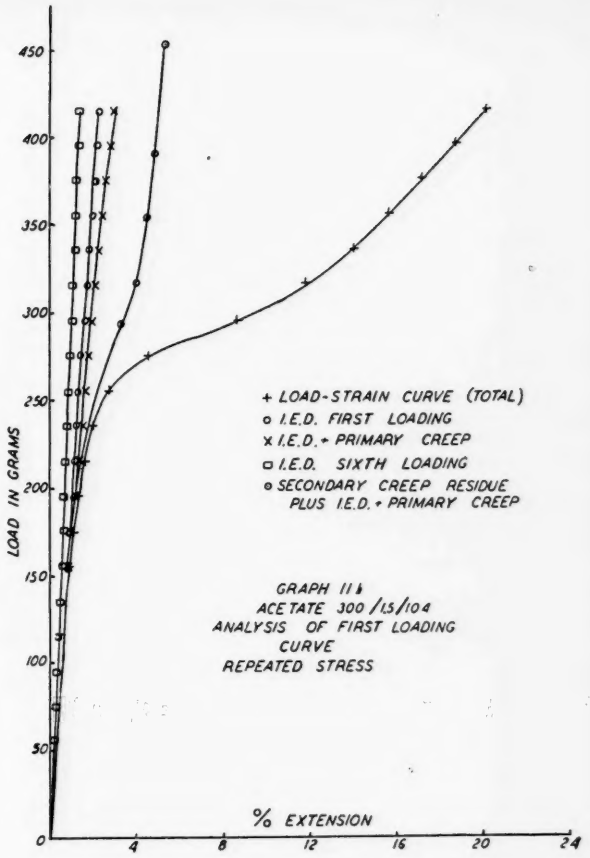

GRAPH 11c
ACETATE 300/15/104
DEFLECTION COMPONENTS
• I.E.D. 6th LOADING
+ PRIMARY CREEP
○ SECONDARY CREEP
LOAD IN GRAMS
% ELONGATION

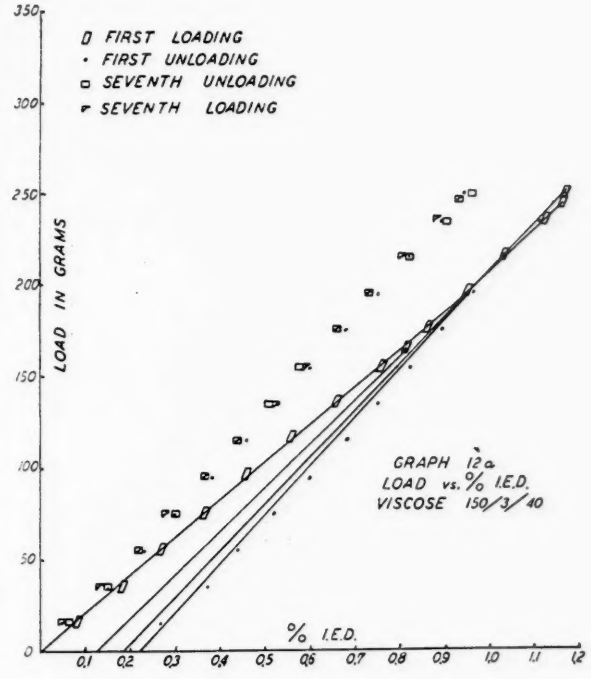

GRAPH 11
STRESS 1/E
ACETATE 300/15/104
I.P.2 and PPM.
□ first loading
• first unloading
▷ sixth loading
□ sixth unloading
STRESS (GRAMS/DEN)
1/E (DENIER/GRAM)


GRAPH 12c
VISCOSE 150/3/40
DEFLECTION COMPONENTS
• I.E.D. 7th LOADING
+ PRIMARY CREEP
● SECONDARY CREEP
LOAD IN GRAMS
% ELONGATION


GRAPH 12
STRESS vs 1/E
VISCOSE 150/3/40
I.P.2 and PPM
□ First loading
• First unloading
▷ Seventh loading
□ Seventh unloading
STRESS (GRAMS/DEN)
1/E (DENIER/GRAM)


FIRST LOADING
FIRST UNLOADING
SIXTH LOADING
SIXTH UNLOADING
LOAD IN GRAMS
% I.E.D.
GRAPH 11a
LOAD vs. % I.E.D.
ACETATE 300/1.5/104


+ LOAD-STRAIN CURVE (TOTAL)
o I.E.D. FIRST LOADING
x I.E.D. + PRIMARY CREEP
□ I.E.D. SIXTH LOADING
o SECONDARY CREEP RESIDUE PLUS I.E.D. + PRIMARY CREEP
LOAD IN GRAMS
% EXTENSION
GRAPH 11 b
ACETATE 300/1.5/104
ANALYSIS OF FIRST LOADING CURVE
REPEATED STRESS


FIRST LOADING
FIRST UNLOADING
SEVENTH UNLOADING
SEVENTH LOADING
LOAD IN GRAMS
% I.E.D.
GRAPH 12a
LOAD vs. % I.E.D.
VISCOSE 150/3/40

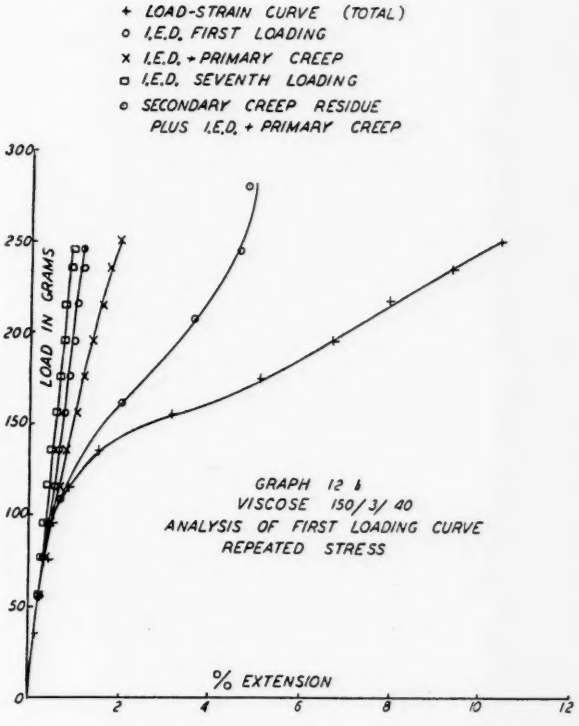

+ LOAD-STRAIN CURVE (TOTAL)
o I.E.D. FIRST LOADING
x I.E.D. + PRIMARY CREEP
□ I.E.D. SEVENTH LOADING
o SECONDARY CREEP RESIDUE PLUS I.E.D. + PRIMARY CREEP
LOAD IN GRAMS
% EXTENSION
GRAPH 12 b
VISCOSE 150/3/40
ANALYSIS OF FIRST LOADING CURVE
REPEATED STRESS

TABLE XI. STRESS-COMPLIANCE DATA FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR ACETATE 300/1.5/104

| 1st loading | | | | | 1st unloading | | | | | 6th loading | | | | | 6th unloading | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *D* | *P* | *P/d* | *t* | 1/*E* | *D* | *P* | *P/d* | *t* | 1/*E* | *D* | *P* | *P/d* | *t* | 1/*E* | *D* | *P* | *P/d* | *t* | 1/*E* |
| 0.0 | 35 | 0.116 | 76.2 | 0.0161 | 0.0 | 35 | 0.139 | 58.5 | 0.00949 | 0.0 | 35 | 0.140 | 57.0 | 0.00899 | 0.0 | 35 | 0.140 | 57.0 | 0.00899 |
| 0.2 | 55 | 0.183 | 76.2 | 0.0161 | 0.2 | 55 | 0.218 | 58.2 | 0.00938 | 0.2 | 55 | 0.220 | 57.0 | 0.00899 | 0.2 | 55 | 0.221 | 56.8 | 0.00893 |
| 0.4 | 75 | 0.250 | 76.0 | 0.0160 | 0.4 | 75 | 0.298 | 57.5 | 0.00915 | 0.4 | 75 | 0.301 | 56.9 | 0.00898 | 0.4 | 75 | 0.302 | 56.1 | 0.00870 |
| 0.6 | 95 | 0.315 | 75.8 | 0.0159 | 0.6 | 95 | 0.378 | 57.1 | 0.00903 | 0.6 | 95 | 0.382 | 56.2 | 0.00875 | 0.6 | 95 | 0.384 | 55.8 | 0.00865 |
| 0.8 | 115 | 0.383 | 75.8 | 0.0159 | 0.8 | 115 | 0.458 | 56.8 | 0.00895 | 0.8 | 115 | 0.462 | 56.0 | 0.00869 | 0.8 | 115 | 0.466 | 55.2 | 0.00845 |
| 1.0 | 135 | 0.450 | 75.6 | 0.0159 | 1.0 | 135 | 0.540 | 56.2 | 0.00875 | 1.0 | 135 | 0.545 | 55.6 | 0.00855 | 1.0 | 135 | 0.546 | 54.8 | 0.00833 |
| 1.2 | 155 | 0.516 | 75.6 | 0.0159 | 1.2 | 155 | 0.620 | 55.9 | 0.00866 | 1.2 | 155 | 0.625 | 55.3 | 0.00847 | 1.2 | 155 | 0.630 | 54.6 | 0.00825 |
| 1.4 | 175 | 0.584 | 75.7 | 0.0159 | 1.4 | 175 | 0.701 | 55.6 | 0.00855 | 1.4 | 175 | 0.709 | 55.0 | 0.00838 | 1.4 | 175 | 0.713 | 54.2 | 0.00813 |
| 1.6 | 195 | 0.659 | 75.6 | 0.0159 | 1.6 | 195 | 0.783 | 55.1 | 0.00840 | 1.6 | 195 | 0.790 | 54.8 | 0.00831 | 1.6 | 195 | 0.797 | 54.0 | 0.00808 |
| 1.8 | 215 | 0.730 | 75.8 | 0.0159 | 1.8 | 215 | 0.864 | 55.0 | 0.00839 | 1.8 | 215 | 0.875 | 54.3 | 0.00816 | 1.8 | 215 | 0.878 | 53.8 | 0.00801 |
| 2.0 | 235 | 0.800 | 75.6 | 0.0159 | 2.0 | 235 | 0.948 | 54.7 | 0.00829 | 2.0 | 235 | 0.957 | 54.2 | 0.00812 | 2.0 | 235 | 0.960 | 53.5 | 0.00792 |
| 2.2 | 255 | 0.871 | 74.9 | 0.0155 | 2.2 | 255 | 1.03 | 54.2 | 0.00813 | 2.2 | 255 | 1.04 | 54.0 | 0.00808 | 2.2 | 255 | 1.05 | 53.3 | 0.00787 |
| 2.4 | 275 | 0.967 | 71.0 | 0.0140 | 2.4 | 275 | 1.11 | 54.1 | 0.00809 | 2.4 | 275 | 1.12 | 53.8 | 0.00803 | 2.4 | 275 | 1.13 | 53.1 | 0.00780 |
| 2.5 | 285 | 1.01 | 68.0 | 0.0128 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 2.6 | 295 | 1.07 | 65.0 | 0.0117 | 2.6 | 295 | 1.19 | 54.0 | 0.00808 | 2.6 | 295 | 1.20 | 53.4 | 0.00791 | 2.6 | 295 | 1.21 | 52.9 | 0.00775 |
| 2.8 | 315 | 1.17 | 61.2 | 0.0104 | 2.8 | 315 | 1.27 | 53.9 | 0.00805 | 2.8 | 315 | 1.29 | 53.2 | 0.00784 | 2.8 | 315 | 1.29 | 52.7 | 0.00769 |
| 3.0 | 335 | 1.27 | 58.9 | 0.00961 | 3.0 | 335 | 1.36 | 53.8 | 0.00800 | 3.0 | 335 | 1.37 | 53.6 | 0.00778 | 3.0 | 335 | 1.38 | 52.6 | 0.00767 |
| 3.2 | 355 | 1.37 | 57.2 | 0.00906 | 3.2 | 355 | 1.43 | 53.8 | 0.00800 | 3.2 | 355 | 1.45 | 52.9 | 0.00775 | 3.2 | 355 | 1.46 | 52.3 | 0.00758 |
| 3.4 | 375 | 1.45 | 56.2 | 0.00876 | 3.4 | 375 | 1.51 | 53.8 | 0.00800 | 3.4 | 375 | 1.54 | 52.6 | 0.00766 | 3.4 | 375 | 1.54 | 52.2 | 0.00755 |
| 3.6 | 395 | 1.56 | 55.0 | 0.00838 | 3.6 | 395 | 1.59 | 53.8 | 0.00800 | 3.6 | 395 | 1.62 | 52.3 | 0.00757 | 3.6 | 395 | 1.63 | 52.1 | 0.00751 |
| 3.8 | 415 | 1.65 | 54.1 | 0.00810 | 3.8 | 415 | 1.66 | 54.1 | 0.00810 | 3.8 | 415 | 1.72 | 52.2 | 0.00753 | 3.8 | 415 | 1.72 | 52.2 | 0.00755 |

NOTE: *D* = chart inches. *P* = load (grams). *P/d* = stress (grams/denier). *t* = time ($\mu$ seconds). 1/*E* = compliance (inverse modulus) in denier/gram.

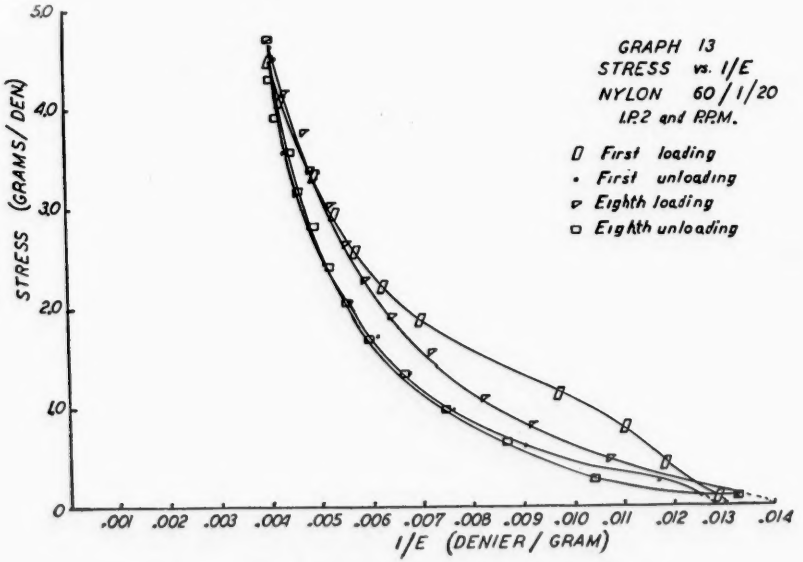
TABLE XII. STRESS-COMPLIANCE DATA FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR VISCOSE 150/3/40

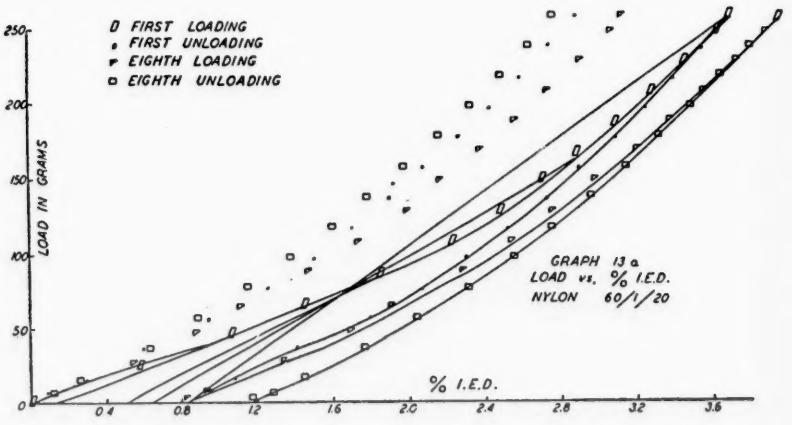
| 1st loading | | | | | 1st unloading | | | | | 7th loading | | | | | 7th unloading | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *D* | *P* | *P/d* | *t* | 1/*E* | *D* | *P* | *P/d* | *t* | 1/*E* | *D* | *P* | *P/d* | *t* | 1/*E* | *D* | *P* | *P/d* | *t* | 1/*E* |
| 0.0 | 15 | 0.100 | 53.0 | 0.00783 | 0.0 | 15 | 0.083 | 45.5 | 0.00577 | 0.0 | 15 | 0.095 | 44.2 | 0.00543 | 0.0 | 15 | 0.110 | 44.4 | 0.00550 |
| 0.2 | 35 | 0.233 | 50.5 | 0.00710 | 0.2 | 35 | 0.255 | 44.3 | 0.00549 | 0.2 | 35 | 0.756 | 43.8 | 0.00534 | 0.2 | 35 | 0.256 | 43.9 | 0.00536 |
| 0.4 | 55 | 0.367 | 50.0 | 0.00695 | 0.4 | 55 | 0.402 | 43.8 | 0.00535 | 0.4 | 55 | 0.402 | 43.2 | 0.00520 | 0.4 | 55 | 0.403 | 43.0 | 0.00514 |
| 0.6 | 75 | 0.500 | 49.9 | 0.00694 | 0.6 | 75 | 0.548 | 43.2 | 0.00520 | 0.6 | 75 | 0.548 | 42.9 | 0.00513 | 0.6 | 75 | 0.562 | 42.6 | 0.00505 |
| 0.8 | 95 | 0.633 | 49.9 | 0.00694 | 0.8 | 95 | 0.698 | 43.0 | 0.00514 | 0.8 | 95 | 0.698 | 42.3 | 0.00500 | 0.8 | 95 | 0.703 | 42.1 | 0.00493 |
| 1.0 | 115 | 0.777 | 49.9 | 0.00694 | 1.0 | 115 | 0.846 | 42.3 | 0.00498 | 1.0 | 115 | 0.846 | 42.0 | 0.00492 | 1.0 | 115 | 0.850 | 41.9 | 0.00491 |
| 1.2 | 135 | 0.925 | 49.9 | 0.00694 | 1.2 | 135 | 0.994 | 42.0 | 0.00492 | 1.2 | 135 | 0.994 | 41.8 | 0.00489 | 1.2 | 135 | 0.998 | 41.2 | 0.00473 |
| 1.4 | 155 | 1.07 | 48.0 | 0.00641 | 1.4 | 155 | 1.14 | 42.0 | 0.00492 | 1.4 | 155 | 1.14 | 41.5 | 0.00481 | 1.4 | 155 | 1.15 | 41.2 | 0.00473 |
| 1.6 | 175 | 1.24 | 45.8 | 0.00586 | 1.6 | 175 | 1.29 | 41.6 | 0.00483 | 1.6 | 175 | 1.29 | 41.3 | 0.00475 | 1.6 | 175 | 1.31 | 40.9 | 0.00467 |
| 1.8 | 195 | 1.39 | 44.4 | 0.00550 | 1.8 | 195 | 1.44 | 41.4 | 0.00478 | 1.8 | 195 | 1.44 | 41.0 | 0.00468 | 1.8 | 195 | 1.47 | 40.7 | 0.00462 |
| 2.0 | 215 | 1.54 | 43.4 | 0.00525 | 2.0 | 215 | 1.59 | 41.2 | 0.00473 | 2.0 | 215 | 1.59 | 40.8 | 0.00465 | 2.0 | 215 | 1.65 | 40.7 | 0.00462 |
| 2.2 | 235 | 1.72 | 42.6 | 0.00505 | 2.2 | 235 | 1.74 | 41.2 | 0.00473 | 2.2 | 235 | 1.77 | 40.6 | 0.00459 | 2.2 | 235 | 1.82 | 40.6 | 0.00450 |
| 2.3 | 245 | 1.79 | 42.0 | 0.00492 | 2.4 | 245 | 1.81 | 41.4 | 0.00478 | 2.3 | 245 | 1.88 | 40.5 | 0.00457 | 2.4 | 245 | 1.90 | 40.5 | 0.00457 |
| | | | | | 2.5 | 250 | 1.84 | 42.0 | 0.00492 | | | | | | 2.5 | 250 | 1.93 | 40.5 | 0.00457 |

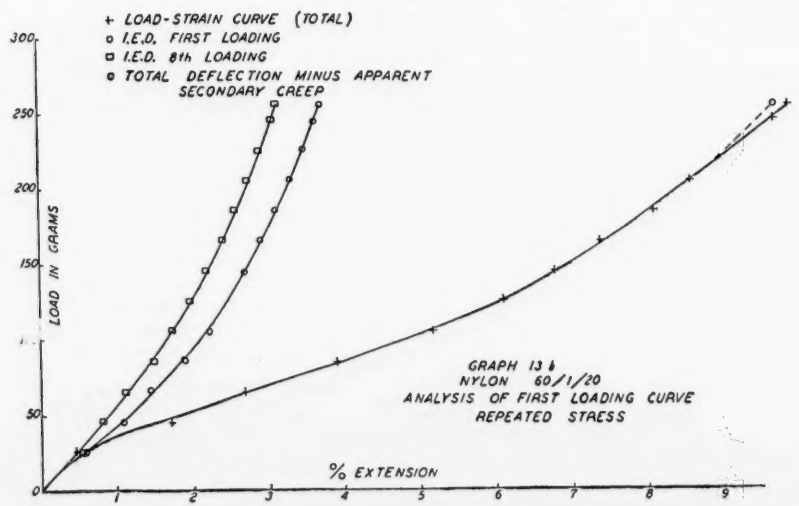
NOTE: Each value represents 1 determination. *D* = chart inches. *P* = load (grams). *P/d* = stress (grams/denier). *t* = time ($\mu$ seconds). 1/*E* = compliance (inverse modulus) in denier/gram.

pliance (inverse modulus) in denier/gram.





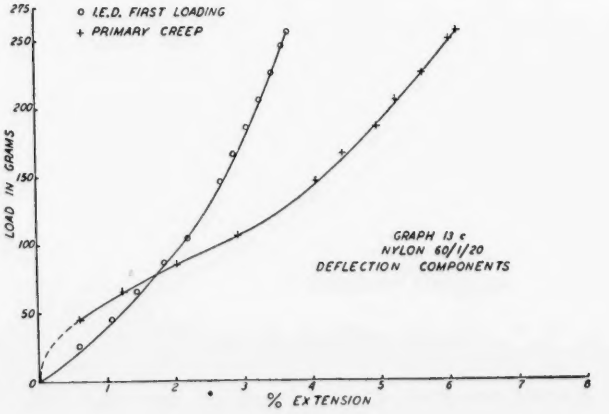



TABLE XIII. STRESS-COMPLIANCE DATA FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR NYLON 60/1/20

| 1st loading | | | | 1st unloading | | | | 8th loading | | | | 8th unloading | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $D$ | $P$ | $P/d$ | $t$ | $1/E$ | $D$ | $P$ | $P/d$ | $t$ | $1/E$ | $D$ | $P$ | $P/d$ | $t$ | $1/E$ | $D$ | $P$ | $P/d$ | $t$ | $1/E$ |
| 0.0 | 5 | 0.083 | 68.0 | 0.0128 | 0.0 | 5 | 0.085 | 67.0 | 0.0125 | 0.0 | 5 | 0.085 | 69.0 | 0.01325 | 0.0 | 5 | 0.085 | 69.0 | 0.01325 |
| 0.2 | 25 | 0.419 | 65.4 | 0.0118 | 0.1 | 15 | 0.261 | 65.0 | 0.0117 | 0.2 | 25 | 0.450 | 62.0 | 0.0107 | 0.1 | 15 | 0.261 | 59.8 | 0.00990 |
| 0.4 | 45 | 0.763 | 63.0 | 0.0110 | 0.3 | 35 | 0.615 | 56.9 | 0.0090 | 0.4 | 45 | 0.800 | 57.5 | 0.00915 | 0.3 | 35 | 0.615 | 55.8 | 0.00864 |
| 0.6 | 65 | 1.12 | 59.2 | 0.0097 | 0.5 | 55 | 0.973 | 52.3 | 0.00758 | 0.6 | 65 | 1.07 | 54.2 | 0.00815 | 0.5 | 55 | 0.973 | 51.8 | 0.00745 |
| 0.8 | 85 | 1.47 | 55.0 | 0.00840 | 0.7 | 75 | 1.34 | 49.2 | 0.00673 | 0.8 | 85 | 1.55 | 51.0 | 0.00722 | 0.7 | 75 | 1.34 | 48.8 | 0.00661 |
| 1.0 | 105 | 1.84 | 50.0 | 0.00695 | 0.9 | 95 | 1.71 | 46.7 | 0.00606 | 1.0 | 105 | 1.92 | 48.1 | 0.00643 | 0.9 | 95 | 1.71 | 46.2 | 0.00595 |
| 1.2 | 125 | 2.21 | 47.2 | 0.00620 | 1.1 | 115 | 2.08 | 44.7 | 0.00556 | 1.2 | 125 | 2.29 | 46.0 | 0.00590 | 1.1 | 115 | 2.08 | 44.5 | 0.00551 |
| 1.4 | 145 | 2.58 | 45.1 | 0.00567 | 1.3 | 135 | 2.45 | 42.8 | 0.00510 | 1.4 | 145 | 2.66 | 44.4 | 0.00550 | 1.3 | 135 | 2.45 | 43.0 | 0.00515 |
| 1.6 | 165 | 2.95 | 43.5 | 0.00525 | 1.5 | 155 | 2.82 | 41.5 | 0.00480 | 1.6 | 165 | 3.03 | 43.0 | 0.00515 | 1.5 | 155 | 2.82 | 41.9 | 0.00489 |
| 1.8 | 185 | 3.33 | 42.0 | 0.00490 | 1.7 | 175 | 3.19 | 40.4 | 0.00455 | 1.8 | 185 | 3.40 | 41.6 | 0.00481 | 1.7 | 175 | 3.19 | 40.5 | 0.00455 |
| 2.0 | 205 | 3.71 | 40.4 | 0.00455 | 1.9 | 195 | 3.57 | 39.4 | 0.00430 | 2.2 | 205 | 3.77 | 41.4 | 0.00478 | 1.9 | 195 | 3.57 | 39.8 | 0.00440 |
| 2.2 | 225 | 4.10 | 39.2 | 0.00428 | 2.1 | 215 | 3.93 | 38.8 | 0.00416 | 2.0 | 225 | 4.14 | 39.5 | 0.00432 | 2.1 | 215 | 3.93 | 38.7 | 0.00415 |
| 2.4 | 245 | 4.49 | 38.4 | 0.00410 | 2.3 | 235 | 4.30 | 38.3 | 0.00405 | 2.4 | 245 | 4.51 | 38.5 | 0.00414 | 2.3 | 235 | 4.30 | 38.2 | 0.00404 |
| 2.5 | 255 | 4.67 | 38.4 | 0.00410 | 2.5 | 255 | 4.66 | 38.4 | 0.00410 | 2.5 | 255 | 4.66 | 38.3 | 0.00405 | 2.5 | 255 | 4.66 | 38.3 | 0.00405 |

NOTE: Each value represents 1 determination. $D$ = chart inches. $P$ = load (grams). $P/d$ = stress (grams/denier). $t$ = time ($\mu$ seconds). $1/E$ = compliance (inverse modulus) in denier/gram.

3. An instrument has been developed which is simple in operation, responsive, rapid, and precise, for the measurement of moduli of elasticity and for the determination of immediate elastic deflections of polymeric materials under all conditions enumerated in (1) and (2) above.

4. Effects of the visco-elastic behavior of high polymers upon their stress-strain relationships have been determined.

5. Both primary and secondary creep affect the modulus of elasticity. Primary creep causes recoverable increases and secondary creep non-recoverable increases in its value.

6. Moduli of elasticity of the materials investigated are a function of:

(*a*) Inherent material properties.

(*b*) The state of strain to which the system is subjected.

(*c*) Previous loading history of the specimen.

7. Acetate and viscose exhibit a constant modulus for the range of loads between zero and the yield point for the first loading cycle. The modulus increases in the range from the yield point to rupture of the specimen. Upon successive loading, no constant modulus region is again obtained.

8. Nylon does not exhibit a constant modulus for any load range. The modulus increases with load, but unlike those for acetate and viscose, the initial and final values of modulus are reproducible for repeated loading cycles.

9. The immediate elastic deflections, as derived from the modulus of elasticity, are affected by primary creep and secondary creep, and are directly related to $1/E$.

10. The yield point of non-Hookean materials may be determined from the stress versus $1/E$ curve.

11. The attainment of the state of "perfect mechanical conditioning" is indicated by a reproducibility of initial and final moduli for materials subjected to repeated stress application.

12. The sum of the immediate elastic and primary creep deflections at any load equal to or less than the conditioning load is constant for all loading cycles. Decreases in immediate elastic deflections due to "cold working" effects of primary creep and secondary creep are accompanied by increases in primary creep of a magnitude sufficient to maintain the sum of immediate elastic and primary creep deflections at the constant limiting value.

13. At the conditioned cycle, the primary creep deflections at lower loads are less than the immediate elastic deflections, whereas at higher loads the immediate elastic deflections are less than the primary creep deflections.

14. The immediate elastic deflection for acetate and viscose is proportional to load for loads below the yield point, but departs from linearity in the region between the yield point and rupture. Measurements made by long-duration creep tests and by analysis of load-elongation tensile tests are not sufficiently precise to reveal the non-linearity which exists for loads beyond the yield point.

15. Nylon does not exhibit a proportionality of immediate elastic deflection to load, for any load range between zero and rupture. The initial value and the final value are reproducible when sufficient time is permitted to elapse between cycles for primary creep recovery.

16. It is probable that for nylon what appears to be a secondary creep deflection at high load values is in reality a delay in recovery of primary creep corresponding to that load.

17. Of the three materials investigated, acetate and viscose fall into a separate and distinct group as compared to nylon. The shapes of the curves of the three deflection components for acetate and viscose are similar, the only difference being in the order of magnitude of the deflection values.

For nylon, not only are the deflection components of different orders of magnitude, but also the deflection curves are of an entirely different shape.

It is suggested that the high elastic performance and abrasion-resistance of nylon are in part due to the high *immediate elastic* energy-absorption capacity of this material.

## Recommendations

1. It has become apparent from laboratory experimental procedures that the I-P-2 tensile testing machine is inadequate for use with the pulse propagation meter for several reasons. The friction and inertia inherent in the loading carriage and loading mechanism introduce spurious loads in the progress of testing, especially at the commencement and the conclusion of a given test.

The load-elongation diagram does not sufficiently amplify the elongations to permit accurate determination of small deflections evidenced by the specimen, and, as a result, early portions of the load-strain curves are not in good agreement with values obtained for immediate elastic and creep deflections.

It is therefore recommended that an electronic-type servo-controlled constant-rate-of-load tensile testing machine, employing a potentiometer recorder, be used in place of the I-P-2 for obtaining constant-rate-of-load results.

2. The problem of minimum crystal pressure and the questionable starting region of the stress versus $1/E$ curves should be investigated further to determine whether or not the distortion of the curve is real.

3. It has been indicated from certain isolated tests, the results of which have not been included in this work, that the modulus of elasticity is a function of the following:

(*a*) Rate of load, elongation, or strain application.

(*b*) Ambient conditions of temperature and humidity.

Since it has been stated that the pulse propagation meter can be successfully employed with variations of the above conditions, it is strongly recommended that further work be done along such lines.

4. Investigations of the visco-elastic properties of natural fibers, especially staple fibers of short length, should be conducted. No difficulty in the use of the pulse propagation meter for such close crystal spacings is anticipated.

## Acknowledgment

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## *Appendix*

TABLE XIV. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR ACETATE 300/1.5/104: 1ST LOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 35 | 0.116 | 1.87 | 0.187 |
| 55 | 0.183 | 3.00 | 0.300 |
| 75 | 0.250 | 4.04 | 0.404 |
| 95 | 0.315 | 5.08 | 0.508 |
| 115 | 0.383 | 6.20 | 0.620 |
| 135 | 0.450 | 7.24 | 0.724 |
| 155 | 0.516 | 8.36 | 0.836 |
| 175 | 0.584 | 9.40 | 0.940 |
| 195 | 0.659 | 10.60 | 1.06 |
| 215 | 0.730 | 11.72 | 1.17 |
| 235 | 0.800 | 12.84 | 1.28 |
| 255 | 0.871 | 13.94 | 1.39 |
| 275 | 0.967 | 15.36 | 1.54 |
| 285 | 1.01 | 15.97 | 1.60 |
| 295 | 1.07 | 16.71 | 1.67 |
| 315 | 1.17 | 17.82 | 1.78 |
| 335 | 1.27 | 18.82 | 1.88 |
| 355 | 1.37 | 19.76 | 1.98 |
| 375 | 1.45 | 20.48 | 2.05 |
| 395 | 1.56 | 21.42 | 2.14 |
| 415 | 1.65 | 22.16 | 2.22 |

TABLE XV. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR ACETATE 300/1.5/104: 1ST UNLOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 35 | 0.139 | 1.35 | 0.135 |
| 55 | 0.218 | 2.11 | 0.211 |
| 75 | 0.298 | 2.86 | 0.286 |
| 95 | 0.378 | 3.59 | 0.359 |
| 115 | 0.458 | 4.31 | 0.431 |
| 135 | 0.540 | 5.02 | 0.502 |
| 155 | 0.620 | 5.72 | 0.572 |
| 175 | 0.701 | 6.41 | 0.641 |
| 195 | 0.783 | 7.13 | 0.713 |
| 215 | 0.864 | 7.84 | 0.784 |
| 235 | 0.948 | 8.51 | 0.851 |
| 255 | 1.03 | 9.18 | 0.918 |
| 275 | 1.11 | 9.83 | 0.983 |
| 295 | 1.19 | 10.47 | 1.05 |
| 315 | 1.27 | 11.11 | 1.11 |
| 335 | 1.36 | 11.83 | 1.18 |
| 355 | 1.43 | 12.47 | 1.25 |
| 375 | 1.51 | 13.11 | 1.31 |
| 395 | 1.59 | 13.75 | 1.38 |
| 415 | 1.66 | 14.34 | 1.43 |

TABLE XVI. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR ACETATE 300/1.5/104: 6TH LOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 35 | 0.140 | 1.29 | 0.129 |
| 55 | 0.220 | 2.01 | 0.201 |
| 75 | 0.301 | 2.73 | 0.273 |
| 95 | 0.382 | 3.44 | 0.344 |
| 115 | 0.462 | 4.14 | 0.414 |
| 135 | 0.545 | 4.92 | 0.492 |
| 155 | 0.625 | 5.61 | 0.561 |
| 175 | 0.709 | 6.29 | 0.629 |
| 195 | 0.790 | 6.96 | 0.696 |
| 215 | 0.875 | 7.71 | 0.771 |
| 235 | 0.957 | 8.36 | 0.836 |
| 255 | 1.04 | 9.00 | 0.900 |
| 275 | 1.12 | 9.64 | 0.964 |
| 295 | 1.20 | 10.28 | 1.03 |
| 315 | 1.29 | 10.99 | 1.10 |
| 335 | 1.37 | 11.61 | 1.16 |
| 355 | 1.45 | 12.23 | 1.22 |
| 375 | 1.54 | 12.93 | 1.29 |
| 395 | 1.62 | 13.54 | 1.35 |
| 415 | 1.72 | 14.29 | 1.43 |

TABLE XVII. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR ACETATE 300/1.5/104: 6TH UNLOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 35 | 0.140 | 1.26 | 0.126 |
| 55 | 0.221 | 1.98 | 0.198 |
| 75 | 0.302 | 2.69 | 0.269 |
| 95 | 0.384 | 3.44 | 0.344 |
| 115 | 0.466 | 4.18 | 0.418 |
| 135 | 0.546 | 4.76 | 0.476 |
| 155 | 0.630 | 5.43 | 0.543 |
| 175 | 0.713 | 6.10 | 0.610 |
| 195 | 0.797 | 6.83 | 0.683 |
| 215 | 0.878 | 7.47 | 0.747 |
| 235 | 0.960 | 8.11 | 0.811 |
| 255 | 1.05 | 8.82 | 0.882 |
| 275 | 1.13 | 9.44 | 0.944 |
| 295 | 1.21 | 10.06 | 1.01 |
| 315 | 1.29 | 10.68 | 1.07 |
| 335 | 1.38 | 11.29 | 1.13 |
| 355 | 1.46 | 11.90 | 1.19 |
| 375 | 1.54 | 12.51 | 1.25 |
| 395 | 1.63 | 13.12 | 1.31 |
| 415 | 1.72 | 13.73 | 1.37 |

TABLE XVIII. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR VISCOSE 150/3/40: 1ST LOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 15 | 0.100 | 1.63 | 0.0815 |
| 35 | 0.233 | 3.65 | 0.183 |
| 55 | 0.367 | 5.48 | 0.274 |
| 75 | 0.500 | 7.35 | 0.368 |
| 95 | 0.633 | 9.22 | 0.461 |
| 115 | 0.777 | 11.16 | 0.558 |
| 135 | 0.925 | 13.24 | 0.662 |
| 155 | 1.07 | 15.18 | 0.759 |
| 175 | 1.24 | 17.26 | 0.863 |
| 195 | 1.39 | 18.96 | 0.948 |
| 215 | 1.54 | 20.58 | 1.03 |
| 235 | 1.72 | 22.44 | 1.12 |
| 245 | 1.79 | 23.14 | 1.16 |

TABLE XIX. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR VISCOSE 150/3/40: 1ST UNLOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 15 | 0.083 | 1.01 | 0.051 |
| 35 | 0.255 | 2.98 | 0.149 |
| 55 | 0.402 | 4.50 | 0.225 |
| 75 | 0.548 | 6.08 | 0.304 |
| 95 | 0.698 | 7.63 | 0.382 |
| 115 | 0.846 | 9.14 | 0.457 |
| 135 | 0.994 | 10.62 | 0.531 |
| 155 | 1.14 | 11.99 | 0.599 |
| 175 | 1.29 | 13.45 | 0.678 |
| 195 | 1.44 | 14.89 | 0.745 |
| 215 | 1.59 | 16.32 | 0.816 |
| 235 | 1.74 | 17.74 | 0.887 |
| 245 | 1.81 | 18.41 | 0.921 |
| 250 | 1.84 | 18.81 | 0.941 |

TABLE XX. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR VISCOSE 150/3/40: 7TH LOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 15 | 0.095 | 1.05 | 0.053 |
| 35 | 0.256 | 2.83 | 0.142 |
| 55 | 0.402 | 4.31 | 0.216 |
| 75 | 0.548 | 5.86 | 0.293 |
| 95 | 0.698 | 7.38 | 0.369 |
| 115 | 0.846 | 8.87 | 0.444 |
| 135 | 0.994 | 10.35 | 0.518 |
| 155 | 1.14 | 11.71 | 0.586 |
| 175 | 1.29 | 13.15 | 0.658 |
| 195 | 1.44 | 14.56 | 0.728 |
| 215 | 1.59 | 15.97 | 0.799 |
| 235 | 1.77 | 17.63 | 0.882 |
| 245 | 1.88 | 18.66 | 0.933 |
| 250 | 1.93 | — | — |

TABLE XXI. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR VISCOSE 150/3/40: 7TH UNLOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 15 | 0.110 | 1.22 | 0.061 |
| 35 | 0.256 | 2.85 | 0.148 |
| 55 | 0.403 | 4.31 | 0.216 |
| 75 | 0.562 | 5.94 | 0.297 |
| 95 | 0.703 | 7.34 | 0.367 |
| 115 | 0.850 | 8.81 | 0.441 |
| 135 | 0.998 | 10.26 | 0.513 |
| 155 | 1.15 | 11.68 | 0.584 |
| 175 | 1.31 | 13.18 | 0.659 |
| 195 | 1.47 | 14.67 | 0.734 |
| 215 | 1.65 | 16.34 | 0.817 |
| 235 | 1.82 | 17.94 | 0.897 |
| 245 | 1.90 | 18.67 | 0.934 |
| 250 | 1.93 | 18.94 | 0.947 |

TABLE XXII. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR NYLON 60/1/20: 1ST LOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 5 | 0.083 | 1.11 | 0.111 |
| 25 | 0.419 | 5.84 | 0.584 |
| 45 | 0.763 | 10.67 | 1.07 |
| 65 | 1.12 | 14.26 | 1.43 |
| 85 | 1.47 | 18.46 | 1.85 |
| 105 | 1.84 | 22.31 | 2.23 |
| 125 | 2.21 | 24.76 | 2.48 |
| 145 | 2.58 | 26.97 | 2.70 |
| 165 | 2.95 | 29.04 | 2.90 |
| 185 | 3.33 | 31.02 | 3.10 |
| 205 | 3.71 | 32.85 | 3.29 |
| 225 | 4.10 | 34.61 | 3.46 |
| 245 | 4.49 | 36.29 | 3.63 |
| 255 | 4.67 | 37.05 | 3.71 |

TABLE XXIII. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR NYLON 60/1/20: 1ST UNLOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 5 | 0.085 | 1.13 | 0.113 |
| 15 | 0.261 | 2.65 | 0.265 |
| 35 | 0.615 | 6.03 | 0.603 |
| 55 | 0.973 | 9.94 | 0.994 |
| 75 | 1.34 | 12.61 | 1.26 |
| 95 | 1.71 | 14.98 | 1.50 |
| 115 | 2.08 | 17.12 | 1.71 |
| 135 | 2.45 | 19.12 | 1.91 |
| 155 | 2.82 | 20.97 | 2.10 |
| 175 | 3.19 | 22.71 | 2.27 |
| 195 | 3.57 | 24.41 | 2.44 |
| 215 | 3.93 | 25.96 | 2.60 |
| 235 | 4.30 | 27.48 | 2.75 |
| 255 | 4.66 | 29.03 | 2.90 |

TABLE XXIV. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR NYLON 60/1/20: 8TH LOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 5 | 0.085 | 1.17 | 0.117 |
| 25 | 0.450 | 5.29 | 0.529 |
| 45 | 0.800 | 8.79 | 0.879 |
| 65 | 1.07 | 11.14 | 1.11 |
| 85 | 1.55 | 14.83 | 1.48 |
| 105 | 1.92 | 17.35 | 1.74 |
| 125 | 2.29 | 19.64 | 1.96 |
| 145 | 2.66 | 21.78 | 2.18 |
| 165 | 3.03 | 23.78 | 2.38 |
| 185 | 3.40 | 25.63 | 2.56 |
| 205 | 3.77 | 27.41 | 2.74 |
| 225 | 4.14 | 29.11 | 2.91 |
| 245 | 4.51 | 30.70 | 3.07 |
| 255 | 4.66 | 31.33 | 3.13 |

TABLE XXV. IMMEDIATE ELASTIC DEFLECTIONS FROM PULSE-PROPAGATION PROCEDURE (REPEATED STRESS) FOR NYLON 60/1/20: 8TH UNLOADING

| Load (g.) | Stress (g./den.) | Area (sq. in.) | % I.E.D. |
|---|---|---|---|
| 5 | 0.085 | 1.15 | 0.115 |
| 15 | 0.261 | 2.60 | 0.260 |
| 35 | 0.615 | 6.01 | 0.601 |
| 55 | 0.933 | 8.85 | 0.885 |
| 75 | 1.34 | 11.48 | 1.15 |
| 95 | 1.71 | 13.81 | 1.38 |
| 115 | 2.08 | 15.95 | 1.60 |
| 135 | 2.45 | 17.94 | 1.79 |
| 155 | 2.82 | 19.83 | 1.98 |
| 175 | 3.19 | 21.60 | 2.16 |
| 195 | 3.57 | 23.31 | 2.33 |
| 215 | 3.93 | 24.86 | 2.49 |
| 235 | 4.30 | 26.38 | 2.64 |
| 255 | 4.66 | 27.82 | 2.78 |

TABLE XXVI. RESIDUAL IMMEDIATE ELASTIC RECOVERIES (REPEATED STRESS) FOR ACETATE 300/1.5/104: 1ST UNLOADING

| Load (g.) | Area (sq. in.) | % I.E.R. | 1st loading % I.E.D. | % I.E.R. residual |
|---|---|---|---|---|
| 0 | — | — | 2.22 | 2.22 |
| 35 | 0.59 | 0.059 | 2.22 | 2.16 |
| 55 | 1.23 | 0.123 | 2.22 | 2.10 |
| 75 | 1.87 | 0.187 | 2.22 | 2.03 |
| 95 | 2.51 | 0.251 | 2.22 | 1.97 |
| 115 | 3.23 | 0.323 | 2.22 | 1.90 |
| 135 | 3.87 | 0.387 | 2.22 | 1.83 |
| 155 | 4.51 | 0.451 | 2.22 | 1.77 |
| 175 | 5.16 | 0.516 | 2.22 | 1.70 |
| 195 | 5.83 | 0.583 | 2.22 | 1.64 |
| 215 | 6.50 | 0.650 | 2.22 | 1.57 |
| 235 | 7.21 | 0.721 | 2.22 | 1.50 |
| 255 | 7.93 | 0.793 | 2.22 | 1.43 |
| 275 | 8.62 | 0.862 | 2.22 | 1.36 |
| 295 | 9.32 | 0.932 | 2.22 | 1.29 |
| 315 | 10.03 | 1.00 | 2.22 | 1.22 |
| 335 | 10.75 | 1.07 | 2.22 | 1.14 |
| 355 | 11.48 | 1.15 | 2.22 | 1.07 |
| 375 | 12.23 | 1.22 | 2.22 | 1.00 |
| 395 | 12.99 | 1.30 | 2.22 | 0.92 |
| 415 | 14.34 | 1.43 | 2.22 | 0.79 |

TABLE XXVII. RESIDUAL IMMEDIATE ELASTIC RECOVERIES (REPEATED STRESS) FOR VISCOSE 150/3/40: 1ST UNLOADING

| Load (g.) | Area (sq. in.) | % I.E.R. | 8th loading % I.E.D. | % I.E.R. residual |
|---|---|---|---|---|
| 0 | — | — | 1.16 | 1.16 |
| 15 | 0.40 | 0.040 | 1.16 | 1.14 |
| 35 | 1.07 | 0.054 | 1.16 | 1.11 |
| 55 | 2.49 | 0.125 | 1.16 | 1.03 |
| 75 | 3.92 | 0.196 | 1.16 | 0.96 |
| 95 | 5.36 | 0.268 | 1.16 | 0.89 |
| 115 | 6.82 | 0.341 | 1.16 | 0.82 |
| 135 | 8.19 | 0.410 | 1.16 | 0.75 |
| 155 | 9.67 | 0.484 | 1.16 | 0.68 |
| 175 | 11.18 | 0.559 | 1.16 | 0.60 |
| 195 | 12.73 | 0.637 | 1.16 | 0.52 |
| 215 | 14.31 | 0.716 | 1.16 | 0.44 |
| 235 | 15.83 | 0.792 | 1.16 | 0.37 |
| 245 | 17.80 | 0.890 | 1.16 | 0.27 |
| 250 | 18.81 | 0.941 | 1.16 | 0.22 |

TABLE XXVIII. RESIDUAL IMMEDIATE ELASTIC RECOVERIES (REPEATED STRESS) FOR NYLON 60/1/20: 1ST UNLOADING

| Load (g.) | Area (sq. in.) | % I.E.R. | 1st loading % I.E.D. | % I.E.R. residual |
|---|---|---|---|---|
| 0 | — | — | 3.71 | 3.71 |
| 5 | 1.55 | 0.155 | 3.71 | 3.55 |
| 15 | 3.07 | 0.307 | 3.71 | 3.40 |
| 35 | 4.62 | 0.462 | 3.71 | 3.25 |
| 55 | 6.32 | 0.632 | 3.71 | 3.08 |
| 75 | 8.06 | 0.806 | 3.71 | 2.90 |
| 95 | 9.91 | 0.991 | 3.71 | 2.72 |
| 115 | 11.91 | 1.19 | 3.71 | 2.52 |
| 135 | 14.05 | 1.41 | 3.71 | 2.30 |
| 155 | 16.42 | 1.64 | 3.71 | 2.07 |
| 175 | 19.09 | 1.91 | 3.71 | 1.80 |
| 195 | 23.00 | 2.30 | 3.71 | 1.41 |
| 215 | 26.38 | 2.64 | 3.71 | 1.07 |
| 235 | 27.90 | 2.79 | 3.71 | 0.92 |
| 255 | 29.03 | 2.90 | 3.71 | 0.81 |

TABLE XXIX. RESIDUAL IMMEDIATE ELASTIC RECOVERIES (REPEATED STRESS) FOR NYLON 60/1/20: 8TH LOADING

| Load (g.) | 8th loading % I.E.D. | 1st recovery % I.E.R. residual | 8th loading % I.E.R. residual |
|---|---|---|---|
| 0 | — | — | 0.81 |
| 5 | 0.117 | 0.81 | 0.93 |
| 25 | 0.529 | 0.81 | 1.34 |
| 45 | 0.879 | 0.81 | 1.69 |
| 65 | 1.11 | 0.81 | 1.92 |
| 85 | 1.48 | 0.81 | 2.29 |
| 105 | 1.74 | 0.81 | 2.55 |
| 125 | 1.96 | 0.81 | 2.76 |
| 145 | 2.18 | 0.81 | 2.99 |
| 165 | 2.38 | 0.81 | 3.19 |
| 185 | 2.56 | 0.81 | 3.37 |
| 205 | 2.74 | 0.81 | 3.55 |
| 225 | 2.91 | 0.81 | 3.72 |
| 245 | 3.07 | 0.81 | 3.88 |
| 255 | 3.13 | 0.81 | 3.94 |

TABLE XXX. RESIDUAL IMMEDIATE ELASTIC RECOVERIES (REPEATED STRESS) FOR NYLON 60/1/20: 8TH UNLOADING

| Load (g.) | Area (sq. in.) | % I.E.R. | 8th loading % I.E.D. | % I.E.R. residual |
|---|---|---|---|---|
| 0 | — | — | 3.94 | 3.94 |
| 5 | 1.44 | 0.144 | 3.94 | 3.80 |
| 15 | 2.96 | 0.296 | 3.94 | 3.64 |
| 35 | 4.51 | 0.451 | 3.94 | 3.49 |
| 55 | 6.22 | 0.622 | 3.94 | 3.32 |
| 75 | 7.99 | 0.799 | 3.94 | 3.14 |
| 95 | 9.88 | 0.988 | 3.94 | 2.95 |
| 115 | 11.87 | 1.19 | 3.94 | 2.75 |
| 135 | 14.01 | 1.40 | 3.94 | 2.54 |
| 155 | 16.34 | 1.63 | 3.94 | 2.31 |
| 175 | 18.97 | 1.90 | 3.94 | 2.04 |
| 195 | 21.81 | 2.18 | 3.94 | 1.76 |
| 215 | 25.22 | 2.52 | 3.94 | 1.42 |
| 235 | 26.67 | 2.67 | 3.94 | 1.27 |
| 255 | 27.82 | 2.78 | 3.94 | 1.16 |

TABLE XXXI. STRESS-STRAIN DATA: LOADING TO RUPTURE

| Acetate 300/1.5/104 | | | | Viscose 150/3/40 | | | | Nylon 60/1/20 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $P$ | $\% \frac{\Delta L}{L_0}$ | $d$ | $P/d$ | $P$ | $\% \frac{\Delta L}{L_0}$ | $d$ | $P/d$ | $P$ | $\% \frac{\Delta L}{L_0}$ | $d$ | $P/d$ |
| 465 | 24.2 | 241 | 1.93 | 305 | 13.9 | 132 | 2.31 | 345 | 19.5 | 50.4 | 6.85 |
| 455 | 23.2 | 244 | 1.87 | 295 | 13.0 | 133 | 2.22 | 325 | 14.0 | 52.6 | 6.19 |
| 435 | 21.4 | 246 | 1.77 | 275 | 12.1 | 134 | 2.05 | 305 | 12.1 | 53.5 | 5.70 |
| 415 | 19.5 | 251 | 1.65 | 255 | 11.2 | 135 | 1.89 | 285 | 11.2 | 53.6 | 5.32 |
| 395 | 18.6 | 253 | 1.56 | 235 | 9.8 | 137 | 1.72 | 265 | 10.7 | 53.7 | 4.94 |
| 375 | 16.7 | 258 | 1.45 | 215 | 8.4 | 138 | 1.56 | 245 | 10.2 | 54.0 | 4.54 |
| 355 | 15.8 | 259 | 1.37 | 195 | 7.4 | 140 | 1.39 | 225 | 9.8 | 54.6 | 4.13 |
| 335 | 13.9 | 263 | 1.28 | 175 | 6.0 | 141 | 1.24 | 205 | 9.2 | 54.9 | 3.74 |
| 315 | 11.1 | 270 | 1.17 | 165 | 5.1 | 142 | 1.16 | 185 | 8.4 | 55.2 | 3.35 |
| 295 | 8.3 | 276 | 1.07 | 155 | 4.6 | 143 | 1.09 | 165 | 7.6 | 55.7 | 2.96 |
| 275 | 4.6 | 287 | 0.959 | 145 | 3.7 | 145 | 1.00 | 145 | 7.2 | 56.0 | 2.59 |
| 255 | 2.8 | 292 | 0.875 | 135 | 2.8 | 146 | 0.925 | 125 | 6.5 | 56.4 | 2.21 |
| 235 | 2.3 | 294 | 0.800 | 115 | 1.4 | 148 | 0.776 | 105 | 5.6 | 56.9 | 1.85 |
| 215 | 1.9 | 295 | 0.729 | 95 | 0.9 | 149 | 0.638 | 85 | 4.7 | 57.3 | 1.49 |
| 195 | 1.4 | 296 | 0.658 | — | — | — | — | 65 | 3.7 | 57.9 | 1.12 |
| — | — | — | — | — | — | — | — | 45 | 2.3 | 58.5 | 0.77 |
| — | — | — | — | — | — | — | — | 25 | 1.4 | 59.1 | 0.423 |
| — | — | — | — | — | — | — | — | 5 | 0.5 | 60.0 | 0.12 |

NOTE: $P$ = load in grams. $d_0$ = original denier. $d$ = denier corresponding to load $P$. $\frac{\Delta L}{L_0}$ = strain at load $P$ based on original length.

TABLE XXXII. STRESS-STRAIN DATA (REPEATED STRESS) FOR ACETATE 300/1.5/104

| | 1st loading | | 1st unloading | | 6th loading | | 6th unloading | |
|---|---|---|---|---|---|---|---|---|
| $P$ | $\% \frac{\Delta L_T}{L_0}$ | $P/d$ | $\% \frac{\Delta L_T}{L_0}$ | $P/d$ | $\% \frac{\Delta L_T}{L_0}$ | $P/d$ | $\% \frac{\Delta L_T}{L_0}$ | $P/d$ |
| 55 | 0.133 | 0.183 | 18.9 | 0.218 | 20.6 | 0.220 | 20.7 | 0.221 |
| 75 | 0.200 | 0.250 | 19.2 | 0.298 | 20.7 | 0.301 | 20.9 | 0.302 |
| 95 | 0.333 | 0.315 | 19.5 | 0.378 | 20.9 | 0.382 | 21.1 | 0.384 |
| 115 | 0.533 | 0.383 | 19.7 | 0.458 | 20.9 | 0.462 | 21.4 | 0.466 |
| 135 | 0.666 | 0.450 | 19.9 | 0.540 | 21.2 | 0.545 | 21.5 | 0.546 |
| 155 | 0.867 | 0.516 | 20.1 | 0.620 | 21.3 | 0.625 | 21.6 | 0.630 |
| 175 | 1.00 | 0.584 | 20.2 | 0.701 | 21.4 | 0.709 | 21.8 | 0.713 |
| 195 | 1.27 | 0.659 | 20.5 | 0.783 | 21.5 | 0.790 | 22.1 | 0.797 |
| 215 | 1.60 | 0.730 | 20.7 | 0.864 | 21.7 | 0.875 | 22.2 | 0.878 |
| 235 | 2.00 | 0.800 | 20.8 | 0.948 | 21.8 | 0.957 | 22.4 | 0.960 |
| 255 | 2.74 | 0.871 | 20.9 | 1.03 | 22.1 | 1.04 | 22.5 | 1.05 |
| 275 | 4.60 | 0.967 | 21.0 | 1.11 | 22.2 | 1.12 | 22.6 | 1.13 |
| 295 | 8.74 | 1.07 | 21.2 | 1.19 | 22.4 | 1.20 | 22.7 | 1.21 |
| 315 | 11.8 | 1.17 | 21.3 | 1.27 | 22.5 | 1.29 | 22.9 | 1.29 |
| 335 | 14.1 | 1.27 | 21.4 | 1.36 | 22.7 | 1.37 | 23.0 | 1.38 |
| 355 | 15.7 | 1.37 | 21.3 | 1.43 | 22.9 | 1.45 | 23.1 | 1.46 |
| 375 | 17.2 | 1.45 | 21.1 | 1.51 | 23.1 | 1.54 | 23.2 | 1.54 |
| 395 | 18.7 | 1.56 | 20.8 | 1.59 | 23.2 | 1.62 | 23.3 | 1.63 |
| 415 | 20.1 | 1.65 | 20.1 | 1.66 | 23.3 | 1.72 | 23.4 | 1.72 |

NOTE: $P$ = load in grams. $\Delta L_T$ = *total* increase in length corresponding to load $P$. $P/d$ = stress in grams per denier.

TABLE XXXIII. STRESS-STRAIN DATA (REPEATED STRESS) FOR VISCOSE 150/3/40

| | 1st loading | | 1st unloading | | 7th loading | | 7th unloading | |
|---|---|---|---|---|---|---|---|---|
| $P$ | $\%\frac{\Delta L_T}{L_0}$ | $P/d$ | $\%\frac{\Delta L_T}{L_0}$ | $P/d$ | $\%\frac{\Delta L_T}{L_0}$ | $P/d$ | $\%\frac{\Delta L_T}{L_0}$ | $P/d$ |
| 15 | — | 0.100 | 8.3 | 0.083 | 9.6 | 0.095 | 9.6 | 0.110 |
| 35 | 0.133 | 0.233 | 9.2 | 0.255 | 9.6 | 0.256 | 10.0 | 0.256 |
| 55 | 0.267 | 0.367 | 9.6 | 0.402 | 9.6 | 0.402 | 10.1 | 0.403 |
| 75 | 0.400 | 0.500 | 9.8 | 0.548 | 9.8 | 0.548 | 10.4 | 0.562 |
| 95 | 0.533 | 0.633 | 10.1 | 0.698 | 10.1 | 0.698 | 10.7 | 0.703 |
| 115 | 0.867 | 0.777 | 10.2 | 0.846 | 10.2 | 0.846 | 10.8 | 0.850 |
| 135 | 1.53 | 0.925 | 10.4 | 0.994 | 10.4 | 0.994 | 11.0 | 0.998 |
| 155 | 3.20 | 1.07 | 10.5 | 1.14 | 10.5 | 1.14 | 11.1 | 1.15 |
| 175 | 5.20 | 1.24 | 10.7 | 1.29 | 10.7 | 1.29 | 11.2 | 1.31 |
| 195 | 6.74 | 1.39 | 10.9 | 1.44 | 10.9 | 1.44 | 11.3 | 1.47 |
| 215 | 8.00 | 1.54 | 10.9 | 1.59 | 11.1 | 1.60 | 11.5 | 1.65 |
| 235 | 9.40 | 1.72 | 10.9 | 1.74 | 11.3 | 1.77 | 11.6 | 1.82 |
| 245 | 9.50 | 1.79 | 10.7 | 1.81 | 11.5 | 1.88 | 11.6 | 1.90 |
| 250 | 10.47 | 1.84 | 10.5 | 1.84 | 11.6 | 1.93 | 11.6 | 1.93 |

NOTE: $P$ = load in grams. $\Delta L_T$ = *total* increase in length corresponding to load $P$. $P/d$ = stress in grams per denier.

TABLE XXXIV. STRESS-STRAIN DATA (REPEATED STRESS) FOR NYLON 60/1/20

| 1st loading | | | 1st unloading | | |
|---|---|---|---|---|---|
| $P$ | $\%\frac{\Delta L_T}{L_0}$ | $P/d$ | $P$ | $\%\frac{\Delta L_T}{L_0}$ | $P/d$ |
| 5 | — | 0.083 | 5 | 2.7 | 0.085 |
| 25 | 0.50 | 0.419 | 15 | 4.2 | 0.261 |
| 45 | 1.7 | 0.763 | 35 | 5.7 | 0.615 |
| 65 | 2.7 | 1.12 | 55 | 6.1 | 0.973 |
| 85 | 3.9 | 1.47 | 75 | 7.2 | 1.34 |
| 105 | 5.2 | 1.84 | 95 | 7.9 | 1.71 |
| 125 | 6.1 | 2.21 | 115 | 8.3 | 2.08 |
| 145 | 6.8 | 2.58 | 135 | 8.7 | 2.45 |
| 165 | 7.4 | 2.95 | 155 | 9.1 | 2.81 |
| 185 | 8.1 | 3.33 | 175 | 9.4 | 3.19 |
| 205 | 8.6 | 3.71 | 195 | 9.7 | 3.57 |
| 225 | 9.2 | 4.10 | 215 | 9.9 | 3.93 |
| 245 | 9.7 | 4.49 | 235 | 9.9 | 4.30 |
| 255 | 9.9 | 4.67 | 255 | 9.9 | 4.66 |

NOTE: 8th loading and unloading values for $P/d$ duplicate those for 1st unloading within 2%. $P$ = load in grams. $\Delta L_T$ = *total* increase in length corresponding to load $P$. $P/d$ = stress in grams per denier.

TABLE XXXV. STRESS-STRAIN DATA: CONTINUED LOADING, REPEATED STRESS—% I.E.D. + % PRIMARY CREEP

| Acetate 300/1.5/104 6th loading | | | | Viscose 150/3/40 7th loading | | | |
|---|---|---|---|---|---|---|---|
| $P$ | $P/d$ | $\Delta L_C$ | $\%\frac{\Delta L_C}{L_0}$ | $P$ | $P/d$ | $\Delta L_C$ | $\%\frac{\Delta L_C}{L_0}$ |
| 55 | 0.221 | 0.02 | 0.133 | 15 | 0.095 | 0.00 | 0.000 |
| 75 | 0.302 | 0.04 | 0.266 | 35 | 0.256 | 0.01 | 0.067 |
| 95 | 0.384 | 0.07 | 0.466 | 55 | 0.402 | 0.03 | 0.200 |
| 115 | 0.466 | 0.08 | 0.533 | 75 | 0.548 | 0.05 | 0.333 |
| 135 | 0.546 | 0.12 | 0.800 | 95 | 0.698 | 0.08 | 0.533 |
| 155 | 0.630 | 0.13 | 0.867 | 115 | 0.846 | 0.10 | 0.667 |
| 175 | 0.713 | 0.15 | 1.00 | 135 | 0.994 | 0.13 | 0.867 |
| 195 | 0.797 | 0.17 | 1.14 | 155 | 1.14 | 0.16 | 1.07 |
| 215 | 0.878 | 0.20 | 1.34 | 175 | 1.29 | 0.18 | 1.20 |
| 235 | 0.960 | 0.22 | 1.47 | 195 | 1.44 | 0.21 | 1.40 |
| 255 | 1.05 | 0.25 | 1.67 | 215 | 1.59 | 0.24 | 1.60 |
| 275 | 1.13 | 0.27 | 1.80 | 235 | 1.77 | 0.27 | 1.80 |
| 295 | 1.21 | 0.29 | 1.94 | 250 | 1.93 | 0.30 | 2.00 |
| 315 | 1.29 | 0.31 | 2.07 | | | | |
| 335 | 1.38 | 0.34 | 2.27 | | | | |
| 355 | 1.46 | 0.37 | 2.47 | | | | |
| 375 | 1.54 | 0.40 | 2.67 | | | | |
| 395 | 1.63 | 0.42 | 2.80 | | | | |
| 415 | 1.72 | 0.44 | 2.94 | | | | |

NOTE: $P$ = load in grams. $P/d$ = stress in grams per denier. $\Delta L_C$ = conditioned loading curve extensions in inches. $L_0$ = original gage length (15 inches).

# Continuous-Filament Casein Yarn*

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**Abstract**

A process for producing continuous-filament casein yarn by pot-spinning is described. The fiber has a tensile strength of 1.0–1.2 grams per denier, elongation of 50 percent, excellent softness, and warmth. Fiber evaluation indices are presented.

ARTIFICIAL PROTEIN FIBER would be expected to have unique properties as a continuous-filament yarn. Its warmth, softness, hand, and range of colors with acid dyes would give the textile designer a new material for use in both woven and knitted goods. With these ideas in mind, studies on the development of continuous-filament casein yarn were initiated in 1945. The process developed is reported in this paper. It is closely related to the staple-fiber process reported previously [8], but major modifications were required to increase the rate of hardening and to prevent adhesion between the filaments.‡

## Equipment and Test Methods

The equipment used (Figure 1) was essentially that described in the previous publication, with the addition of a rayon centrifuge pot operating at either 3,600 or 5,000 r.p.m. A ventilating hood has been added to the machine since the photograph was taken, for the removal of formaldehyde vapor given off by the treatment bath.

Denier was determined by weighing 9 cm. of the yarn on a micro-torsion balance. Tenacity and elongation were determined by breaking 2-inch gage lengths of these 9-cm. samples on a Scott I-P-2 Serigraph. Dry tests were carried out at 70°F and 65 percent relative humidity. Wet tenacity was determined after the weighed samples had been soaked for ½ hour in individual test tubes of distilled water. Ten tests were averaged in each case. The fiber evaluation indices proposed by Smith [10] were calculated from these data. Stiffness of the tow was determined in an arbitrary manner. A number of pieces of yarn were mounted in parallel in an Olsen-Tour-Marshall 0.5-inch-pound model stiffness tester, and the resistance to bending was measured.

Work recovery was determined on single filaments by a single-fiber autographic tester [11]. The area under the recovery curve divided by the area under the extension curve, expressed as a percentage, is the work recovery for any selected elongation.

## Experimental Procedure

The major steps in the new process are: (*A*) preparation of the spinning solution, (*B*) spinning it into a precipitating bath, (*C*) simultaneous stretching and treating in a heated stretch bath, (*D*) adjusting the pH in a treatment bath, (*E*) collecting the tow in the centrifuge pot, (*F*) storing, washing, and drying the cake, and (*G*) stabilizing the fiber by after-treatment. Each step has been investigated in considerable detail.

(*A*) The casein solutions were prepared from a high-quality acid-precipitated commercial casein. The casein was mixed with sufficient water and sodium hydroxide to produce a 25-percent solution having a pH of 7. It was then heated to 55°C with constant stirring, and stored overnight at this temperature to deaerate. Phenyl or pyridyl mercuric acetate of 0.025-percent concentration was added in the water as a preservative. These and similar salts are

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† One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture.

‡ Application for a public service patent has been made.

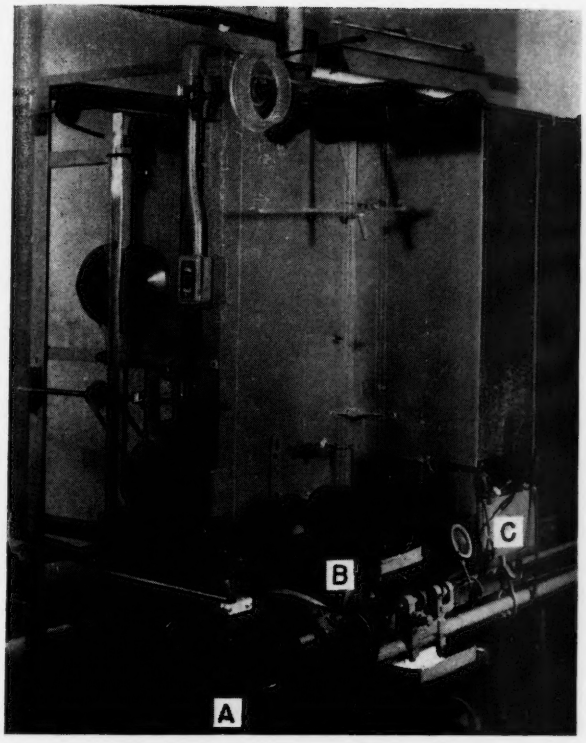


FIG. 1. *Apparatus for spinning continuous-filament casein yarn. A—Rayon-type centrifuge. B—Treatment bath. C—Stretch bath; upper cone godet only is visible.*

excellent preservatives in this pH 7 solution. The usual spinning viscosity was 500–600 poises at 25°C.

(*B*) The highly acid precipitating baths previously employed have been replaced by an acetic acid bath. The new bath enables fine filaments to be spun more readily, for it permits a greater rate of draw-off from the precipitating bath, and there is also less acid carry-over to the stretch bath. Table I gives data which show the composition of the two baths and the effects produced.

TABLE I. COMPOSITION OF PRECIPITATING BATH VERSUS TOW PROPERTIES

| Composition | pH | % Casein in tow* | Max. draw ratio† |
|---|---|---|---|
| 10% $H_2SO_4$, 22% $Na_2SO_4$ | 0.2 | 30 | 1.9 |
| 6% HOAc, 20% $Na_2SO_4$ | 3.5 | 38 | 3.9 |

* Determined by centrifuging skeins to get the wet weight. To get the dry casein weight, the same skein was hardened in formaldehyde to make it insoluble, washed, dried, and weighed.

† Calculated from jet extrusion rate; spinneret 250 0.003-diameter holes; extrusion at 5.4 ml./min.

(*C*) The stretch bath employed contained 10 percent sodium sulfate, 10 percent aluminum sulfate, and 5 percent formaldehyde. The cone godets previously described were used. The lower one was partially immersed in the stretch bath, which was maintained at a definite temperature. A stretch of 100 percent, which absorbed the tendency of the fiber to sag under the treatment, was imposed on the tow by these cones, and additional stretch was introduced after this treatment as the fiber was taken to the next godet wheel. The time of treatment in the stretch bath was approximately 2 minutes.

An increase in tenacity quite similar to that obtained previously with the sulfuric acid baths was observed. (See Table II.)

When the fiber was collected in the centrifuge pot immediately after this treatment, it was stiff and "plastered" together, owing to incomplete hardening. However, two chemical effects of importance occurred during this treatment: formaldehyde and aluminum ion were taken up. The formaldehyde content of the tow coming out of the stretch bath was 2.0 percent, but only 0.5 percent was bound firmly enough to resist washing with water. A reasonable increase in time of treatment in the bath did not increase the percent of bound formaldehyde enough to make this a practicable hardening treatment. About 0.5 percent of aluminum is introduced by the stretch bath. This fact was taken advantage of to produce a supplementary hardening effect in the next step.

(*D*) The fiber was passed through a concentrated (30-percent) sodium acetate bath at pH 6. This treatment presumably precipitates a basic aluminum

TABLE II. INCREASE IN TENACITY BY STRETCHING TO MAXIMUM IN HEATED SALT-$CH_2O$ BATH, FOLLOWING ACETIC-ACID PRECIPITATING BATH*

| Temp. of bath (°C) | Max. obtainable stretch (%) | Tenacity at 70°F, 65% R.H. (g./den.) | Wet tenacity (g./den.) |
|---|---|---|---|
| 27 | 145 | 0.71 | 0.26 |
| 35 | 190 | 0.78 | 0.27 |
| 45 | 215 | 0.83 | 0.32 |
| 55 | 280 | 0.93 | 0.40 |
| 65 | 400 | 1.03 | 0.43 |
| 75 | 530 | 0.95 | 0.46 |
| 60 | 428 | 1.2 | 0.56 |

* Except in the last line of the table, data were obtained at a jet extrusion rate of 4.73 meters a minute, and a take-off speed of 9.15 meters per minute. By lowering the take-off speed to 6.25 meters per minute, the time of contact with the bath is increased, and a higher stretch may be imposed at 60°C.

TABLE III. IMPROVEMENT IN FLEXIBILITY OBTAINED BY USE OF TREATMENT BATH

| No. | Treatment | No. filaments/denier | Stiffness* in in.-lbs. $\times 10^4$ |
|---|---|---|---|
| 1 | No wash bath | 250/400 | 23. |
| 2 | Wash at pH 5 | 250/400 | 16. |
| 3 | Wash at pH 6 | 250/400 | 1.6 |
| — | Commercial viscose yarn, oiled for knitting | 100/300 | 1.6 |

* Arbitrary units, obtained by mounting fibers in parallel in an Olsen-Tour-Marshall 0.5-in.-lb. model stiffness tester.

salt on the surface of the fiber. The individual filaments no longer adhere. The twisting of the tow as it enters the centrifuge does not stiffen it, and the layers of yarn in the cake do not stick. Moreover, the cake of yarn does not shrink subsequently, and denier changes are cut to a minimum. The improvement in the softness of the yarn is marked, as shown in Table III.

(*E*) The fiber was then passed into the centrifuge pot. Cakes have been collected in runs of 6 hours without a break. At pot speed, spinning speeds of 65 meters/minute have been attained.

(*F*) The cake of yarn from the pot may be stored for several hours to complete the formaldehyde reaction, in which case the bound formaldehyde will be about 2 percent. If greater formaldehyde uptake is desired, additional treatment in a 30 percent sodium acetate-5 percent formaldehyde bath at pH 6 is used. The major beneficial effects of formaldehyde are increases in wet tenacity and in flexibility. Formaldehyde treatments at high acidities have been reported to produce boil-stable cross-linkages [14, 4] but we have not observed such an effect. The fiber is ordinarily washed in tap water and dried at 100°F.

(*G*) Of the many methods we have tested of stabilizing the fiber to boiling acid dye baths, acetylation is the best. This method, which is used commercially [1], was the subject of an earlier study in this laboratory [2]. There are marked deviations in the behavior of the highly stretched fiber here described from that of the low-tenacity fiber investigated previously. Moisture content of the fiber is important, for acetic acid exerts a deleterious effect on the dry strength of the fiber. (See Table IV.) Experiments with fibers of different water contents showed a similar effect.

Complete stabilization of the fiber to acid dye baths is not attained by this procedure, but the fiber can be

TABLE IV. ACETYLATION OF CASEIN FIBER FOR 1 HOUR AT 88°C WITH ACETIC ACID AS A CATALYST

| Acetylating solution* | Tenacity at 70°F, 65% R.H. (g./den.) |
|---|---|
| Control | 1.10 |
| 8% $Ac_2O$, 0% HOAc | 1.09 |
| 8% $Ac_2O$, 2% HOAc | 0.98 |
| 8% $Ac_2O$, 4% HOAc | 0.93 |
| 8% $Ac_2O$, 6% HOAc | 0.92 |

* 86–92% petroleum ether, b.p. 88°C, was used as a diluent.

treated with substantive dyes for 1 hour at 80°C without loss of tenacity. Other stabilizing treatments are being investigated.

Interesting results were obtained with a commercial-grade silicone halide containing 25 percent of hydrolyzable chlorine. The casein yarns, which contained about 10 percent of moisture at the start of the treatment, were boiled in a 1-percent silicone halide solution at the reflux temperature of the petroleum ether solvent, which was 38°C. The yarn was centrifuged, dried, and then baked at 120°C for 10 minutes. The minimal result was the raising of the dry strength of the yarn as well as the wet strength. The vapor-phase water absorption of the treated yarn 1018, measured by Dr. E. F. Mellon, was found to be unchanged from the original value. The yarns can be dyed after this treatment. (See Table V.)

## Evaluation and Discussion

The fiber finished by acetylation has some noteworthy properties, which are due in large part to the fiber's high breaking elongation. The load-elongation curves obtained with a Scott I-P-2 Serigraph show

TABLE V. EFFECT OF SILICONE TREATMENT ON TENACITY

| Treatment | Tested at 70°F, 65% R.H. Tenacity (g./den.) | Tested at 70°F, 65% R.H. Elongation (%) | Tested wet Tenacity (g./den.) | Tested wet Elongation (%) |
|---|---|---|---|---|
| Yarn 1018 | | | | |
| Reflux in 1% solution | 1.27 | 50 | 0.68 | 50 |
| | 1.23 | 50 | — | — |
| Untreated control | 1.09 | 50 | 0.50 | 50 |
| Yarn 1020 | | | | |
| Reflux in 1% solution | 1.33 | 45 | 0.59 | 50 |
| Untreated control | 1.11 | 45 | 0.40 | 45 |

TABLE VI. PROPERTIES OF 150-FILAMENT, 300-DENIER YARN

| Fiber | Tested at 70°F, 65% R.H. Tenacity (g./den.) | Elongation at break (%) | Tested wet Tenacity (g./den.) | Elongation at break (%) | Toughness* index (g./den.) | Stiffness† (g./den.) | Elasticity‡ (%) |
|---|---|---|---|---|---|---|---|
| "Raw" | 1.2 | 50 | 0.56 | 45 | 0.30 | 2.4 | 4.5 |
| Acetylated | 1.0 | 50 | 0.49 | 45 | 0.25 | 2.0 | 3.2 |
| Rayon 100/300 | 2.2 | 22 | 1.1 | 30 | 0.24 | 10.0 | 3.2 |

* Area under stress-strain curve to break; $\frac{\text{tenacity} \times \text{elongation } \%}{200}$.

† $\frac{\text{Tenacity} \times 100}{\text{Elongation, } \%}$.

‡ Elongation at the yield point.

distinct reinforcement during the flow process in the dry fiber. Flexibility as measured by knot strength is high. Regain of the fiber is about 14 percent, and the heat evolved on wetting the fiber contributes to the warm feel characteristic of wool. The fineness and the absence of scale structure give it silklike characteristics as well. The fiber evaluation indices of Dr. H. DeW. Smith [10] have been used to evaluate the fiber further. (See Table VI.)

A single-fiber autographic tester made by the Harris Instrument Company has been used to supply further data on the elastic properties of the yarn at low elongations. L. G. Ray [9] had previously noted the high resilience of casein fibers at low elongations. By stretching the fiber at a rate of 1.6 percent elongation per minute to various elongations and then permitting it to recover at the same rate, a more accurate comparison could be made between rayon and casein fibers. The area under the returning part of the curve, or the work recovered, expressed as a percentage of the work required to stretch the fiber to the given elongation, is compared for casein and rayon. (See Table VII.)

Further recovery of the yarn will take place after the load has been completely removed. The similarity of the casein yarn to wool is shown further by the correspondence of the loading and recovery behavior in water. Essentially complete recovery from elongations up to 30 percent is obtained. This property has been observed by Wormell [13]. Since these curves are more responsive to methods of chemical stabilization, they are a means of readily evaluating such treatments [7, 12]. The field of usefulness for continuous-filament casein yarn, as well as the other contemporaneous protein fibers, will be increased by improvements in stability to textile processing.

TABLE VII. PERCENT WORK RECOVERY FOR CASEIN AND RAYON YARNS

| Fiber | Stretch to elongation of: 1% | 2% | 3% |
|---|---|---|---|
| Casein 150/300 | 97 | 77 | 59 |
| Rayon 40/150 | 71 | 36 | 32 |

Recent studies with model compounds have given evidence of the method by which formaldehyde forms cross-linkages in proteins [5]. Since the bridge between amide and amino groups is acid-labile, some of the cross bonds in casein fiber will be removed in acid dye baths. The chemical individuality of casein is such that stabilizing treatments which are effective for other proteins are not necessarily applicable to casein fibers. This is a general principle, for it derives from the differences in composition and structure of the various proteins, as pointed out in a recent review [6].

The success of the pot-spinning process we have developed is based on rapid hardening with basic aluminum salts. Two British patents have been issued on pot-spinning processes [3]. The first avoids the shrinkage difficulty by relaxing the fiber before it enters the pot. The second makes use of a hot-air blast to dry the tow as it enters the centrifuge. The properties of the fiber produced by these processes have not been reported.

Preliminary evaluation of the casein fiber in knitted and woven goods has been made. It has been successfully knitted on circular half-hose machines, and woven into fabrics which exhibit the unusual properties to be expected from such a fiber. It is still deficient in tenacity and resistance to acid dyeing conditions. Research on these and other factors is continuing.

### Acknowledgment

Sincere appreciation is expressed to Dean Richard S. Cox and Mr. John Naab of the Philadelphia Textile Institute for making possible the knitting tests of our fiber, and to Mrs. Jean Maus and Mr. A. R. Buchert for technical assistance.

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## *T.R.J.* Index for 1948

OWING to printing difficulties, the index to Volume XVIII, 1948, does not appear in this issue. It will be printed as a separate publication and mailed to subscribers to Volume XVIII early in 1949.

# Retardation of Heat-Induced Strength Loss in Cotton Yarns by Liquid Ammonia Treatment

**Harry B. Moore**

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**Abstract**

Treatments of cotton in the form of yarns and rovings with liquid ammonia are described. Smaller loss of strength as a result of prolonged heating at 160°C was found in these treated yarns. Since no strength changes were found in the fibers, it is concluded that this was due to a greater tendency of the ammonia-treated cotton to curl and crinkle, which increases the friction between the fibers in the yarn.

THE LOSS of tensile strength of tire cords due to heat, a major cause of the failure of tires, has been of considerable interest. Exploratory work at the Southern Regional Research Laboratory has been done to determine whether this strength loss can be arrested in cotton by chemical treatments. Reid [9, 10] observed that heat-induced degradation of cotton was completely arrested if the sample were immersed in ethanolamine during the heating. Though ethanolamine boils at 172.2°C, the sample can remain in the refluxing liquid for several days without loss of strength. A similar effect was observed by Reese [8] and Hill and Jacobson [5] with urea and biuret, and by Sebrell [12] with a variety of amines.

In preliminary studies of the subject at this laboratory, a group of compounds, most of them nitrogen-containing, was tried. Urea seemed the most promising—it did not increase the hot-breaking strength,† but slowed the permanent degradation produced by long heating, and, also, the effect of the treatment remained after the chemical was washed out. Other basic substances produced heat-resistance as long as the cotton was immersed in or impregnated with them —leading to the conclusion that these substances, which included ordinary sodium carbonate, opposed degradation of the cellulose by neutralizing the acids formed during breakdown by the heat.

Since treatments with fused urea frequently produced some small gains in the strength of yarns after heating, similar compounds were investigated. Oxamide, the first substance investigated, could not be liquefied below a temperature destructive to cellulose, so solutions of the oxamide were tried.

Only with liquid ammonia as the solvent were the effects notable. At first, liquid ammonia was used merely as a solvent capable of producing good impregnation of the cellulose because of its penetrating and swelling effect thereon. But since the oxamide did not seem to have dissolved, it became apparent that the solvent, rather than the solute, was responsible for the strength retention observed. Further studies were therefore performed with liquid ammonia; and various temperatures were tried over a range in time of treatment to discover the optimum conditions. Considering the possibility of hydrolysis occurring during the treatment, a drying agent, barium oxide, was enclosed in the reaction vessel. Though it would damage the cotton if allowed to come into contact with it, when in a separate enclosed tube, its effect was found to be advantageous, so that drying came to be considered important for obtaining good results.

It had been known that liquid ammonia, and many amines, form addition compounds with cellulose [1, 3, 13] which have different x-ray diagrams; and that, under some circumstances, the cellulose does not return to its original state on removal of the amines—that is, the lattice remains different from that of native cellulose. With liquid ammonia, the phenomenon was first observed by Peterson, King, and Barry [6], who also noted that swelling was produced in the fibers.

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† Determined at 130°C, after 5 minutes at this temperature.

Besides attempting to find the conditions of ammonia treatment for maximum strength of cotton yarns and fibers, after heating, a comparison was also made of the strengths of yarns and fibers treated with sodium hydroxide, in which approximately the same amount of swelling was produced by the two reagents.

## Experimental Procedure

### *Samples and Treatments*

Nonextracted cotton rovings and yarns * and alcohol-extracted cotton rovings and yarns were used in the experiments. The alcohol extraction was accomplished by submitting the material in a Soxhlet extractor to at least 16 overflows. A few drops of sodium hydroxide solution were added to the liquid in the boiling flask to prevent any traces of the acids extracted along with waxes from returning to the cotton.

Several varieties of cotton were used, but no significant difference in results was observed with the different varieties of cotton. In the experiments for the comparison of the alkali and ammonia treatments, a uniform Wilds 13 variety, processed into 16.75/2 yarns, with a twist in ply of 9.25 turns per inch, was used.

### *Equipment and Methods*

For reaction vessels, straight lengths of 25-mm. Pyrex tubing were made into the form of ampules. When drying was employed, a small, soft test tube filled with barium oxide was placed over the samples wadded in the bottom.

Since air and moisture were to be avoided in the ammoniations, the gas was condensed thus: The two ends of the straight length of a three-way stopcock were connected by an ordinary piece of flexible rubber tubing to the ammonia tank, and by a length of vacuum tubing to the reaction vessel, already drawn out for sealing. The third arm was connected by a length of vacuum tubing to a vacuum line, or aspirator. When vacuum was applied to the whole system to begin the transfer process, the flexible tubing collapsed. It served as an indicator, during transfer, by the "feel" of the pressure inside. The receiver containing the specimens was then immersed in solid carbon dioxide-acetone, and the stopcock was rotated to connect the receiver and ammonia tank only. Ammonia was then admitted, its transfer being controlled by the "feel" of the flexible tubing. When the receiver was full, the neck, previously drawn out, was sealed off and disconnected with the hand torch.

When treatments were to be made at elevated temperatures, the high vapor pressures inside the tube were counterbalanced by placing the reaction vessel in a hydrogenation bomb and running the pressure up to at least 1,000 pounds per square inch under controlled temperature.

For the sake of uniformity and simplicity, the tubes were opened by bursting at a temperature sufficiently high to avoid undue cooling by evaporation. Hess and Gundermann [4] had found that cellulose-ammonia yields a product which gives an indefinite, amorphous x-ray diagram when allowed to cool under $-20°C$.

The measurement of the retention of strength by specimens heated in an oven at 160°C for 16 hours was used as the test for heat-resistance—that is, this measurement was compared with that of the original specimen before treatment. For comparison and elimination of any variation due to testing conditions, controls and treated yarns and rovings were placed in the oven at the same time.

Yarn strength was determined on the Scott inclined-plane tester, 2,000 grams capacity. Fiber strength was determined on the Pressley tester [7] on fibers removed from roving. Both the yarns and the fibers were conditioned in an atmosphere of 70°F and 65 percent relative humidity for a minimum of 4 hours before the strengths were determined. Each strength recorded represents the average measurement of at least 10 yarns or 10 ribbons of fibers.

## Results

The strengths of treated samples will be given chiefly in percentages of the strengths, before heating, of the corresponding control samples, with nonextracted and extracted samples being considered separately.

### *Effect of Ammonia Treatment*

More than 150 treatments were made on yarn-roving samples, but unless favorable results were obtained from the first experiment with a given temperature-time combination, no further experiments were performed under those conditions. Except for the treatments whose favorable results made it de-

* Yarns and rovings are defined in A.S.T.M. Bulletin D-123, 1947 Supplement to *A.S.T.M. Standards,* Part III-A.

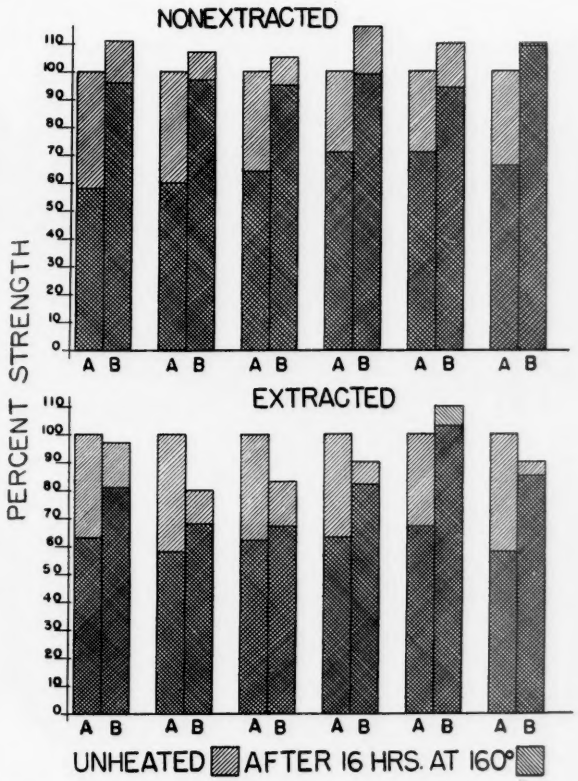


FIG. 1. *Strength of cotton yarns before and after heating for 16 hours at 160°C. Repeat experiments: (A) untreated yarns; (B) yarns treated 3 hours with liquid ammonia. Where the markings are darker, one marking is superimposed upon the other.*

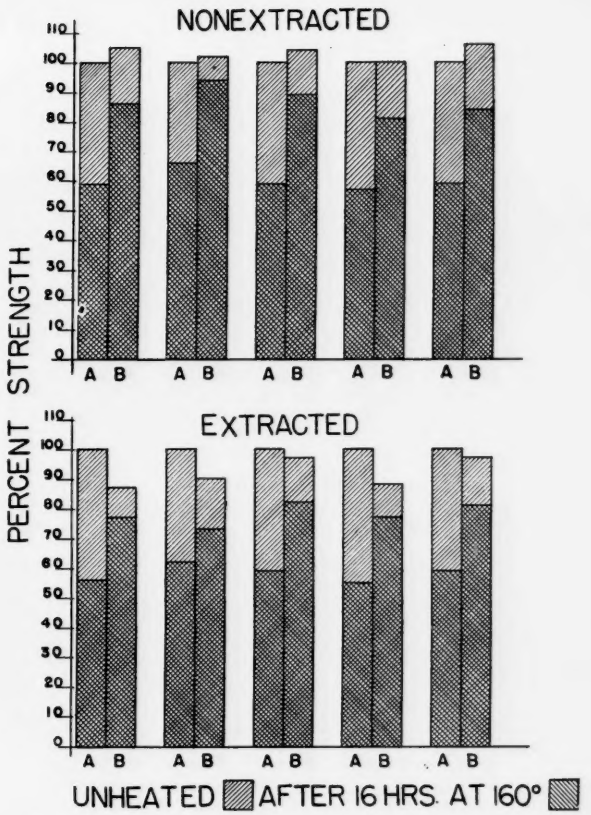


FIG. 2. *Strength of cotton yarns before and after heating for 16 hours at 160°C. (A) untreated yarns; (B) yarns treated 2 hours with liquid ammonia. Where the markings are darker, one marking is superimposed upon the other.*

sirable to repeat them, only those which gave the best result for each stage of processing will be given.

*Yarns—(1) Nonextracted.* The highest percent of strength before test heating, 116 percent, for nonextracted yarns, was obtained after an ammonia treatment of 3 hours at 125°C with barium oxide enclosed.

After heating—with the same treatment—the maximum retention of strength in this yarn was 109 percent (untreated, 66 percent). This yarn strength seemed to be independent of whether or not drying was employed.

*Yarns—(2) Extracted.* "Before heating" percent gains for extracted yarns were much smaller, comparatively, than for nonextracted yarns. Apparently, the extraction produced almost maximum strength. Anything which tended to produce cellulose degradation, such as the elevated temperature used in the treatment, detracted from this strength. Only with further extraction, with ethanolamine, for instance, and with low-temperature ammonia treatments, were gains shown in the unheated extracted yarns. However, the latter treatment gave quite different and inferior results after heating, confirming Hess and Gundermann's findings [4] that different x-ray diagrams result when the ammonia is removed above and below − 20°C.

After heating, these extracted yarns were irregular in strength. The greatest strength, 110 percent (untreated, 67 percent), was produced by an ammonia treatment with barium oxide, for 3 hours at 125°C. This procedure was repeated five times on 5 separate samples and the resulting strengths are shown in Figure 1.

It was noticeable that, on the whole, the yarns which had high strength before treatment and test heating showed, after the heating, percentages of strength lower than those for yarns of lower original strength. This indicates that although the treatment did not actually increase strength it gave re-

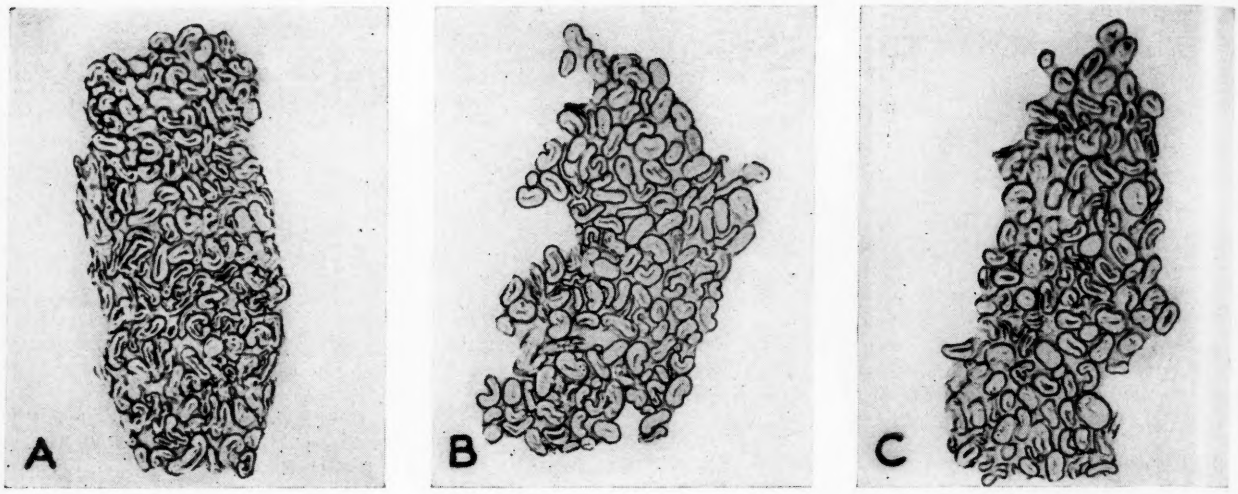


FIG. 3. *Cross-sectional photomicrographs of cotton yarns, unheated: (A) untreated; (B) NaOH-treated; (C) liquid-ammonia-treated. Only one ply of a two-ply yarn is shown. Magnification 250 ×.*

tention of strength during heating. This is visible in the six identical treatments described above, and in the five 2-hour treatments at the same temperature, illustrated in Figure 2.

*Rovings.* Before heating, ammonia treatment of nonextracted rovings resulted in a fiber strength loss of between 7 and 23 percent. In fact, the only improvements observed in fibers, due to the treatment, were some small strength retentions in the heated, nonextracted material. The largest of these was only 5 percent greater than that for the corresponding untreated sample, which is within the limits of variability of the cotton. This lack of difference when the treatment is given would indicate that the retention of strength when the yarns are heated is a property of the yarns which is due to frictional forces between their constituent fibers rather than to an increase in the strength of the fibers. This frictional effect could be expected to appear only after the heating, because strength did not increase appreciably with treatment alone.

*Nitrogen Analysis.* It was definitely determined that ammonolysis did not take place. Nitrogen determinations were as follows:

Extracted control: 0.16 percent, and 0.16 percent.

Ammonia-treated (extracted) specimen: 0.15 percent, and 0.13 percent.*

*X-Ray Studies.* X-ray diagrams were made before and after heating, on treated and untreated specimens. It was observed that the different crystal lattice resulting from the treatment tended, upon heating, to revert slowly toward the original pattern.

*Comparison of Effects of Alkali and Liquid Ammonia on Swelling and Heat-Resistance*

In order to test the hypothesis that the retention of strengths might be the result of frictional forces due to swelling in the fibers, it was decided to compare the effect of swelling produced by alkali to that produced by liquid ammonia treatment. The studies were made on yarns and fibers, as before.

*Yarns.* Using the ammoniation on a special yarn, in determined lengths, the shrinkage was measured. Planimeter measurements were made on at least 150 fibers at each of three cross-sectional points on a 1-foot length of yarn. However, fiber distribution in the yarn caused these to be subject to variations too large to permit their use. As a substitute for equal area, shrinkage in length was made the criterion for determining equal swelling.

Yarns 36 inches in length, measured under a constant tension, were marked with two knots. At least 7 specimens of these were included in a repeat of one of the more favorable treatments found. The shrinkage of these yarns was found to be 10.4 percent. Similar 36-inch specimens were subjected to various concentrations of sodium hydroxide until one was found which produced the same shrinkage as the ammonia treatment. After each immersion in alkali, the yarns were thoroughly washed with several changes of distilled water, followed

* The difference between these percentages is insignificant.

TABLE I. EFFECT OF HEAT AND TREATMENT ON STRENGTH OF NONEXTRACTED AND EXTRACTED YARNS AND FIBERS

| | Treatment | | | | | |
|---|---|---|---|---|---|---|
| | Untreated | | Liquid ammonia 3 hrs. at 125°C | | Swollen in 12.47% NaOH | |
| | Strength (g.) | Standard error (g.) | Strength (g.) | Standard error (g.) | Strength (g.) | Standard error (g.) |
| Cotton Yarns | | | | | | |
| Nonextracted | | | | | | |
| Before heating | 1383 | 19.8 | 1472 | 22.0 | 1498 | 28.1 |
| After 16 hrs. at 160°C | 765 | 12.8 | 1211 | 34.1 | 956 | 30.9 |
| Extracted | | | | | | |
| Before heating | 1832 | 15.2 | 1760 | 34.3 | 1632 | 22.2 |
| After 160 hrs. at 160°C | 1102 | 18.6 | 1424 | 36.5 | 1234 | 28.2 |
| Fibers* | | | | | | |
| Nonextracted | g./grex† | g./grex | g./grex | g./grex | g./grex | g./grex |
| Before heating | 4.47 | 0.054 | 4.20 | 0.05 | — | — |
| After 16 hrs. at 160°C | 3.33 | 0.070 | 3.55 | 0.059 | 3.52 | 0.065 |
| Extracted | | | | | | |
| Before heating | 4.63 | 0.097 | 4.06 | 0.05 | 4.50 | 0.059 |
| After 16 hrs. at 160°C | 4.17 | 0.03 | 3.92 | 0.03 | 4.00 | 0.065 |
| Fluidity | | | | | | |
| (Extracted cotton only) | Rhes | Rhes | Rhes | Rhes | Rhes | Rhes |
| Before heating | 2.03 | 0.04 | 2.49 | 0.01 | 2.50 | 0.04 |
| After 16 hrs. at 160°C | 13.4 | 0.2 | 14.5 | 0.2 | 14.1 | 0.3 |

* Fibers treated in roving form.

† 1 gram/grex = 1.85 Pressley index, since

$$1 \text{ Pressley index} = \frac{1 \text{ pound}}{1 \text{ mg./0.468 inch}} = \frac{454 \text{ grams}}{841 \text{ grex}} = 0.540 \text{ gram/grex},$$

where 1 grex is defined as 1 gram per 10,000 meters [11], and 0.468 inch is the length of the clamping surface of the Pressley jaws.

by another washing for 16 hours (overnight) in 4 liters of distilled water.

When the proper alkali concentration was found, specimens of yarns and rovings were given a treatment, washed thoroughly, conditioned, and tested. Since a difference was found in the shrinkage of unextracted and extracted yarns given the same treatment, the latter were selected for the experiments, since they were the least liable to intrude other factors.

In the extracted yarns, the ammonia treatments reduced the specimen length from 36 to 32.27 inches. Treating the extracted yarns with 12.47-percent sodium hydroxide reduced the specimens to 32.36 inches. Repeat tests on similar yarns treated with sodium hydroxide gave lengths less than 32.27 inches, indicating that variations in shrinkage could be expected with the treatments.

Microscopical examinations of cross sections (Figure 3) of these yarns indicated that swelling in both the ammonia- and alkali-treated extracted yarns appeared to be approximately the same, whereas the nonextracted yarns swelled less in sodium hydroxide than in ammonia—which action corresponded to the shrinkage behavior of the yarns.

In Table I are given the strengths of the extracted and nonextracted yarns and fibers before and after heating. Since the alkali-shrunk specimens were unexpectedly weak after heating, two repeats of this experiment were done. In the second, washing was extended beyond the 4-liter bath to include several more washings in changes of distilled water followed by another overnight washing, as before. This procedure would have removed any trace of alkali or salt left in the samples which might have catalyzed heat degradation and decreased the strength. However, this prolonged washing had no influence on the strength of the yarns.

The data show that the strengths of the fibers were not very different for a given stage, whether untreated, alkali-treated, or ammonia-treated. The ammonia-treated fibers were a little weaker before heating.

As a further study of the degradation of cellulose, fluidity measurements (given in Table I) were made on the extracted cottons [2]. The results, within experimental error, paralleled those obtained in the strength determinations.

Apparently, swelling, in our experiment, was closely related to shrinkage. However, additional

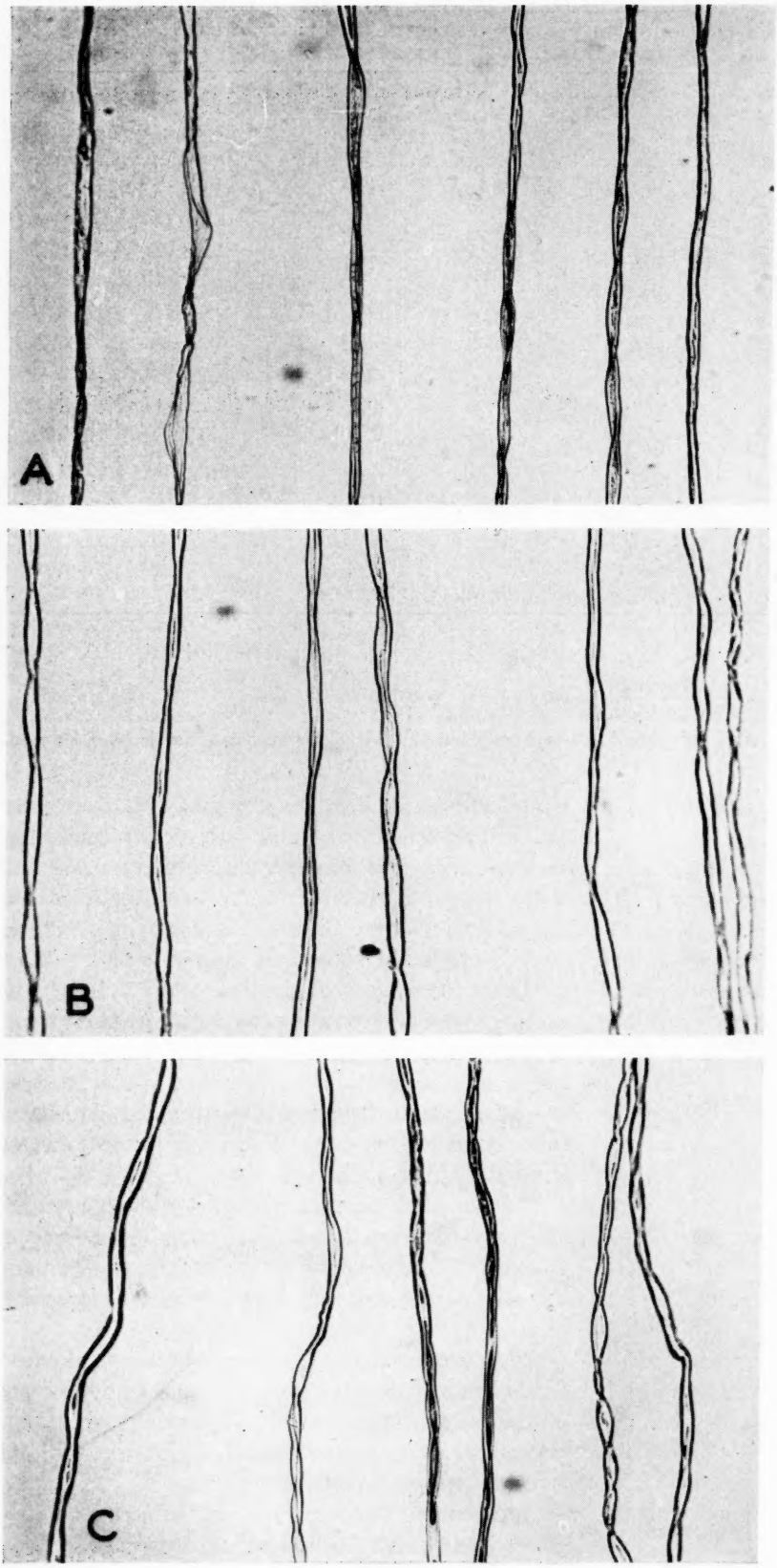


FIG. 4. *Photomicrographs of cotton fibers heated for 16 hours at 160°C. (A) untreated; (B) NaOH-treated; (C) liquid-ammonia-treated. Magnification 125×.*

treatments with sodium hydroxide of concentrations of 12, 13, and 14 percent, were made to determine whether an increase in swelling in this range was reflected in increased strength of yarns. In all cases, the sodium hydroxide-treated yarns proved inferior to the ammonia-treated yarns after exposure to the heating test. And yet the degree of swelling of fibers in the 14-percent alkali was appreciably greater than that found in the ammonia treatments. Hence it was concluded that swelling could not be the mechanism through which fiber friction in ammoniated yarns increased.

*Microscopical Examinations.* In the swelling investigations, transverse cross sections of the fibers had been examined in order to evaluate the effects of the various treatments on the cross-sectional areas. Continuing the search for the causes of the improvement in heated strength of ammonia-treated yarn, small bundles of fibers were extracted from the yarns, paralleled, and examined microscopically in the longitudinal position, both before and after heating. Pronounced differences were visible when the treated and the untreated bundles were viewed longitudinally. The former were much more crinkled, twisted, and convoluted (Figure 4). This crinkling as a result of overnight heating at 160°C was observed in several sets of fibers. In addition, the ammonia-treated samples in-

creased their convolution on heating, afterwards exceeding both the untreated and the alkali-treated in this respect.

## Conclusions

The increase in strength of cotton yarns treated with dry liquid ammonia and heated overnight at 160°C over the strength of the untreated yarns must be due to some frictional effect inside the yarn which comes into play at that temperature, since it is to be observed only in the yarns and not in the fibers, and is not in evidence in strength measurements before heating.

However, the frictional effect must be different from that produced by caustic alkali swelling, because at a shrinkage equal to that produced by liquid ammonia the alkali-treated specimens were much weaker after heating. The x-ray pattern of the ammonia-treated material was definitely changed, and is known to be different from that of mercerized material. The different reaction produced might have been expected because of these known differences in x-ray patterns (the ammonia-created patterns being qualitatively different from those of partial mercerization).

In making the ammonia-sodium hydroxide comparisons, a concentration range of alkali was used which was high enough to swell the cotton but too low to produce the change to "mercerized cotton," of different x-ray pattern, in 100 percent conversion [14].

The results indicate that swelling is not the explanation of the greater strength retention of ammonia-treated yarns. The 13- and 14-percent sodium hydroxide treatments in some cases caused swellings greater than the swelling due to ammonia, yet there was little difference in yarn strengths after heating, and all strengths were lower than that of the ammoniated yarns. The explanation, on the evidence of the microscopic observations of increased convolution in ammoniated constituent fibers, is apparently the increase in "clinging-together" of the fibers in the yarns caused by crimping and twisting of the material at the elevated temperature of the test heating.

## Acknowledgment

The author is indebted to Miss Ines V. deGruy for the photomicrographs, Mr. M. E. Jefferson for the x-ray examinations, and Mr. Verne W. Tripp for the fluidity measurements.

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(*Manuscript received October 13, 1948.*)

# Laboratory Techniques

## An Improved Permanent Mounting Medium for Textile Fibers

H. H. Broadfoot* and E. R. Schwarz†

BY THE COMBINATION of a synthetic resin of moderately low refractive index with a compatible plasticizer of a much higher index, a colorless permanent mount for textile fibers can be made which has the desired refractive index.‡ A good index is far enough from that of the fiber (either higher or lower) to give good structural details of the fiber. A single mounting medium with a refractive index that is approximately halfway between the maximum and minimum indices of the common fibers has been found to be most useful. By varying the composition of the mixture, it is possible to adjust the refractive index to a value more suitable for a particular fiber. (See Table I.)

Isobutyl methacrylate polymer (Du Pont) of refractive index 1.48 and Aroclor 1242 (Monsanto) of refractive index 1.62 were, respectively, the resin and the plasticizer used for the mount described in this report. Both materials are colorless and quite miscible with xylene. The proportions of all three materials were adjusted until a viscous liquid was obtained which had a refractive index of approximately 1.52.

This index is about halfway between the indices for cotton or wool and for acetate rayon. The index commonly given for cotton is 1.56, for wool is 1.55, and for acetate rayon is 1.48.

The following is the formula for a permanent mounting medium (after heating) of a refractive index between 1.515 and 1.520.

| | |
|---|---|
| Xylene (filtered) | 21 cc. |
| Aroclor 1242 | 9 cc. |
| Isobutyl methacrylate polymer | 18 g. |

The isobutyl methacrylate polymer should be ground in a mortar to remove lumps and thus hasten the solution. A round, 2-ounce bottle, or the 2-ounce square type commonly used for dye samples, will hold the above amounts conveniently. The filtered xylene is poured into the bottle. Next, the Aroclor 1242 is added. Then the isobutyl methacrylate polymer is placed in the solution. The mixture is stirred for about 5 minutes, or until a homogeneous mass is obtained. After stirring, the mix is allowed to stand for a few hours, or overnight, until all the bubbles produced in the stirring have passed off. There remains a colorless liquid of a viscosity very close to that which is usual with solutions of Canada balsam. The I.B.M. polymer is not chemically pure; hence

TABLE I. APPROXIMATE REFRACTIVE INDICES OF VARIOUS MIXTURES

| Formula | | | |
|---|---|---|---|
| Isobutyl methacrylate polymer | Aroclor 1242 | Xylene | Refractive index of finished mount |
| 18 g. | — | 30 cc. | Between 1.495 and 1.500 |
| 18 g. | 3 cc. | 27 cc. | Between 1.495 and 1.500 |
| 18 g. | 6 cc. | 24 cc. | Between 1.505 and 1.510 |
| 18 g. | 9 cc. | 21 cc. | Between 1.515 and 1.520 |
| 18 g. | 12 cc. | 18 cc. | Between 1.520 and 1.525 |

TABLE II. APPROXIMATE REFRACTIVE INDICES OF SOME COMMON FIBERS

| | |
|---|---|
| Acetate rayon | 1.48 |
| Sisal | 1.53 |
| Nitrate rayon | 1.53 |
| Viscose rayon (bright) | 1.53 |
| Vinyon | 1.54 |
| Cuprammonium rayon | 1.54 |
| Wool | 1.55 |
| Nylon | 1.55 |
| Cotton | 1.56 |
| Hemp (Italian) | 1.56 |
| Flax | 1.56 |
| Ramie | 1.56 |
| Silk | 1.57 |

* Research Assistant, Textile Division, Massachusetts Institute of Technology.

† In charge: Textile Division, Massachusetts Institute of Technology.

‡ In this article the term "refractive index," when applied to fibers (see Table II for listing), means the average refractive index in monochromatic sodium light.

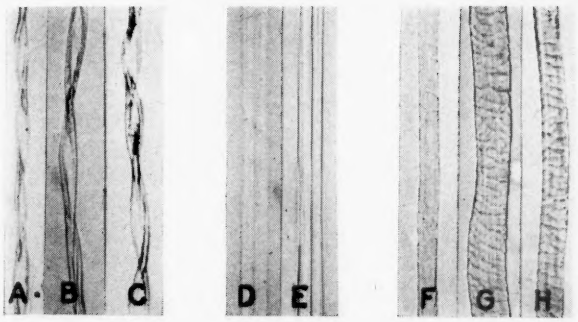


FIG. 1. (*See Table III.*) *Photomicrographs of various fibers mounted in various mounting media.*

minute impurities remain suspended throughout the material. These do not seem to interfere with the visibility of the mounted fiber. On long standing, these minute impurities settle to the bottom of the medium leaving it quite clear.

The procedure is as follows:

Use in the same manner as Canada balsam. Press the cover glass flat. Enough material should be used so that a slight excess exudes around the edges of a square cover glass. Heat in an oven at 70°C for at least 2 hours, or, better still, overnight. With some media, air bubbles are often formed under the cover glass. With this mounting medium these bubbles usually disappear on heating in the oven, especially on heating overnight. When hard, the excess material is removed by a single-edged razor blade, leaving the cover glass clean around the edges.

Positioning the fibers on the microscope slide can be done accurately by the use of masking tape if the fibers are of sufficient length. The ends of the fiber are attached to the slide with small bits of tape approximately ⅜ inch square. Many fibers may be attached in this way, as close as desired. Then a longer, narrow piece of the tape is placed perpendicularly across all the fibers inside the tapes holding each of the fiber ends, and is then ironed flat with the end of the tweezers. Do this for each set of ends. This is to ensure that all the fibers are in the same plane, which would not be true otherwise. All the pieces of tape should be placed at a point which will be outside the cover glass when the latter is placed in position. The mounting medium can be dropped on the fibers from a pointed glass rod (pointed to limit the size of the drop). Another advantage of anchoring the fibers with tape is that when the cover glass is pressed flat over the fibers they will move from their original positions only slightly, if at all.

TABLE III. DATA FOR THE PHOTOMICROGRAPHS SHOWN IN FIGURE 1

| Photomicrograph | Fiber | Refractive index | Mounting medium | Refractive index | Visibility |
|---|---|---|---|---|---|
| A | Cotton | 1.56 | Canada balsam | 1.54 | Poor |
| B | Cotton | 1.56 | Isobutyl methacrylate Formula with 9 cc. Aroclor 1242 | Between 1.515 and 1.520 | Good |
| C | Cotton | 1.56 | Formula with 3 cc. Aroclor 1242 | Between 1.495 and 1.500 | Good |
| D | Acetate rayon | 1.48 | Formula with 3 cc. Aroclor 1242 | Between 1.495 and 1.500 | Very poor |
| E | Acetate rayon | 1.48 | Formula with 9 cc. Aroclor 1242 | Between 1.515 and 1.520 | Good |
| F | Wool | 1.55 | Canada balsam | 1.54 | Poor |
| G | Wool | 1.55 | Formula with 9 cc. Aroclor 1242 | Between 1,515 and 1.520 | Good |
| H | Wool | 1.55 | Formula with 3 cc. Aroclor 1242 | Between 1.495 and 1.500 | Good |

A different technique can be employed if the fibers are shorter than the width of the cover glass. Each end of each fiber can be tacked down with a pin point of the mounting medium placed there with the dissecting needle, and then dried in the oven. Proceed as before in the positioning of the cover glass.

The advantages of this mounting medium, besides its permanency, are that it is colorless and that its refractive index can be changed for a particular fiber by varying the proportions of Aroclor 1242 used. It is not found practical to use much more than the highest amount of Aroclor 1242 given in Table III, for with larger amounts a mixture would be formed which would contain too high a proportion of non-hardening material. Also, it would approach too near the refractive index of the cotton or wool and other fibers of about the same refractive index as these. Although this might be a somewhat better

mounting for the acetate rayon, it would be a poorer medium for the cotton and wool than that given in the formula. The reverse is true when the amount of Aroclor 1242 is decreased. The resulting fluid may be a little better for the cotton or wool but poorer for the acetate rayon. It has been found, too, that there is a tendency for bubbles to develop in the finished mount if only I.B.M. polymer is used. The formula given was an average suitable for most common fibers. (See Table III and Figure 1.)

Also, because of the saturated nature of the mixture, methyl methacrylate embedded sections can be mounted in it. Normally, the methyl methacrylate polymer would be dissolved by the xylene or xylene solutions of other mounting media not so saturated.

The refractive index of the finished mount is determined in monochromatic sodium light by noting the direction of movement of the Becke line on focusing up of the microscope from sharp focus on the edge of the fiber. The Becke line moves toward the material of higher refractive index under these conditions. The solid material for each formula was obtained by drying a thin layer of the liquid mixture on a microscope slide at 70°C overnight and then cutting small pieces for immersion in the various fluids of known refractive index.

A more accurate determination of the refractive index for the solid mounting medium than noting the range as given was thought to be unnecessary. The fluid, being a mixture which solidifies by the evaporation of one of its constituents, could vary slightly in the third decimal place of its refractive index. Such variation, although it prevents an accurate determination of the refractive index of the finished material, is not sufficient to alter the usefulness of the mixture.

*(Manuscript received October 27, 1948.)*

# ABSTRACTS

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*A list of periodicals abstracted, the abbreviations used in references to articles, and the addresses of publishers of English language publications is given in the January, 1948, issue, page 48.*

## ANALYSIS: TESTING: LABORATORY METHODS

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### Dynamic Mechanical Properties

**Methods for measuring dynamic mechanical properties of rubberlike materials.** A. W. Noble. *J. Applied Phys.* **19,** 753–74 (Aug. 1948).

Five methods for measuring the complex differential dynamic Young's modulus of rubberlike materials are described. Formulas are derived for calculating the complex modulus. The practical advantages and limitations of each method are given. L. P. Witnauer

*Text. Research J. Dec. 1948*

### Electron Microscopy

**Chromatic aberration and resolving power in electron microscopy.** E. G. Ramberg and J. Hillier. *J. Applied Phys.* **19,** 678–82 (July 1948).

Employment of dark-field observation in electron microscopy introduces the complication that the imaging electrons are inhomogeneous. Calculations of the effect of chromatic aberration and diffraction show that the resolution is not appreciably affected when an objective aperture smaller than the "optimum aperture" and centered optics are used. L. P. Witnauer

*Text. Research J. Dec. 1948*

### Resilience Measurement

**The over-all specific volume, compressibility and resilience of fibrous materials.** W. Howard Rees. *J. Text. Inst.* **39,** T131–41 (Apr. 1948).

A method is described for measuring the over-all specific volume, compressibility and resilience of fibrous materials. Experimental data for certain fibers are presented. It is shown that the over-all specific volume of fibers in bulk depends upon their previous treatment even though the fibers are orientated as indiscriminately as possible before the measurement is carried out. It is also shown that, in measurements of resilience, the use of a hollow rigid cylinder for containing the fibers should be avoided since it leads to errors due to friction between the fibers and the cylinder wall. Author

*Text. Research J. Dec. 1948*

### Spectrophotometric Technique

**An application of spectrophotometry in the textile industry: Testing dyestuff shipments.** E. P. Mersereau and J. L. Barach. TEXTILE RESEARCH JOURNAL **18,** 436–9 (July 1948).

Newer spectrophotometric techniques for the absorption measure-

***ABSTRACT REPRINTS***

*The* JOURNAL *is again offering to its subscribers reprints of the Abstracts and Book Review sections, printed on one side of the sheet so that the items may be clipped, pasted on cards, and filed for permanent reference. Subscription to this service for 1949 is $3.50. Orders for this special service for 1949 should be mailed at once to Textile Research Institute, Inc., 10 East 40th Street, New York 16, N. Y.*

ments of solutions of dyestuffs to determine their strengths are compared to the traditional methods of testing dyestuff shipments by visual appraisal of yarns or fabrics dyed by standard procedures. Sampling errors are measured and discussed in relation to a control-chart method of handling the resultant information. Various examples are cited. Authors
*Text. Research J. Dec. 1948*

## Abrasion Test

**Taber yarn-sheet abrasion test.** E. M. Hicks and A. G. Scroggie. TEXTILE RESEARCH JOURNAL **18,** 416–23 (July 1948).

A technique is described for the determination of yarn abrasion-resistance free from other wear factors such as flexibility, strength, elongation, and fabric construction. The procedure is based on a sheet of parallel yarns wound under controlled tension and subsequently abraded to failure on a Taber Abraser. The method has been used to evaluate the effect of yarn properties as well as fiber type on yarn abrasion-resistance. Results for yarns correlate well with the Taber abrasion-resistance of fabrics made from these yarns, and can be used to determine the inherent yarn abrasion-resistance without the necessity of fabric preparation. Authors
*Text. Research J. Dec. 1948*

## Viscometer

**A penetroviscometer for very viscous liquids.** J. J. Bikerman. *J. Colloid Sci.* **3,** 75–85 (May 1948).

The viscometer in which the viscosity is determined by the rate descent of a heavy vertical rod in a coaxial tube filled with the liquid measures viscosities ranging from $10^{-2}$ to $10^{-6}$ poises with an accuracy of $\pm 1$ to 2%. Data are given on an 80% solution of rosin in turpentine and a 70% solution of rosin in benzyl benzoate. E. D. Klug
*Text. Research J. Dec. 1948*

## Viscosity of Oils

**The Cragoe L function for the viscosity of oils under pressure at certain temperatures.** R. B. Dow. *J. Colloid Sci.* **3,** 99–109 (May 1948).

The Cragoe L function which gives the change of viscosity of lubricating oils with pressure, temperature, and composition has been determined for 12 representative petroleum oils over a pressure range of 28,000 lb./in.$^2$ at 100°, 130°, and 210°F. The discrepancies between measurements and theory are discussed and are suggested to be due to orientation effects. E. D. Klug
*Text. Research J. Dec. 1948*

## Young's Modulus Determination

**The bending modulus of animal fibres.** R. M. Khayatt and N. H. Chamberlain. *J. Text. Inst.* **39,** T185–97 (May 1948).

Parallel determinations of Young's modulus by bending and stretching at 65% R.H. and 22.2°C have been made on fibers drawn from samples of three different types of animal fibers, and one type has also been examined after descaling by abrasion. The results show that in all cases the values of the modulus by bending are less, not greater, than those of the modulus by stretching, and that the effect of descaling is to reduce both moduli to approximately the same extent. A new microapparatus for the determination of Young's modulus by bending, using wool fibers and human hair, is described and its use explained. Authors
*Text. Research J. Dec. 1948*

# CHEMICAL AND PHYSICAL RESEARCH

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## Hydrate Cellulose

**Transformation of hydrated cellulose to natural cellulose. X. Influence of ultrasonic waves on the transformation.** Teruichiro Kubo. *J. Soc. Chem. Ind. Japan* **44,** 939–41 (1941); cf. *C.A.* **42,** 2429*a* (through *Chem. Abstr.* **42,** 2766*d* (Apr. 20, 1948)).

The transition from hydrated to natural cellulose is made much easier by the preliminary application of ultrasonic waves to the material immersed in a polar medium. The effect is due to the destabilization of the crystal lattice by mechanical vibration. When the transition treatment is carried out on a molecular compound of hydrated cellulose after applying ultrasonic waves, the interference point of natural cellulose in x-ray pictures begins to show itself at a lower temperature than in the sample without such preliminary treatment. These phenomena are based on the action of ultrasonic waves in stimulating the solvation and in increasing the mobility of hydrated cellulose molecules. The temperature of transition is greatly influenced by the change in the degree of solvation.
*Text. Research J. Dec. 1948*

## Cellulose and Heavy Water

**Rate of exchange of cellulose with heavy water.** V. J. Frilette, J. Hanse, and H. Mark. *J. Am. Chem. Soc.* **70,** 1107–13 (Mar. 1948).

Cellulose in the form of wood pulp, rayon fibers, or native cotton fibers reacts very rapidly with heavy water provided sufficient agitation is used. This rapid reaction is complete in less than 1 hr. but is followed by a slower reaction which persists for days. The reaction is a replacement of OH of the cellulose by the OD from the heavy water. The influence of temperature and pH on the reaction is negligible. The techniques used and the calculation involved are discussed. The extent of the rapid reaction is a measure of the accessibility of the cellulose sample and hence may be used to determine the amount of amorphous cellulose present. Results were 21% in cotton, 46% in wood pulp, and 66% in rayon. The relationships of these results with accessibility values found by the thallation method, by hydrolytic methods, and by density methods are discussed.
A. R. Macormac
*Text. Research J. Dec. 1948*

## Sodium Carboxymethyl Cellulose

**The effect of sodium carboxymethyl cellulose on synthetic detergent systems.** Thomas H. Vaughn and Clifton E. Smith. *J. Am. Oil Chemists' Soc.* **25**, 44–51 (Feb. 1948). *See also abridgment:* **Sodium CMC in synthetic detergents.** Thomas H. Vaughn and H. Earl Tremain. *Soap Sanit. Chemicals* **24**, 37–9, 98 (Mar. 1948).

Certain forms of sodium carboxymethyl cellulose have been shown to be highly effective as synthetic detergent promoters. Formulations containing a sodium alkyl-aryl sulfonate-type of synthetic detergent, alkaline salts, and a type of sodium carboxymethyl cellulose developed for high detergency-promoting properties surpass high-quality fatty acid soaps in both carbon soil removal and whiteness retention on cottons. Ternary diagrams have been presented for systems containing Kreelon 4D, a sodium alkyl-aryl sulfonate-type of detergent; Carbose, a commercial-detergent grade of sodium carboxymethyl cellulose; and each of 4 alkaline salts. From these diagrams can be selected visually an infinite number of formulations having any desired level of detergency within the range covered, which will meet other requirements such as maximum or minimum foaming, high or low alkaline salt content, etc. Sodium carboxymethyl cellulose promotes detergency in both hard water and diluted synthetic sea water, and, in fact, has actual water-softening properties, being able to sequester or otherwise reduce the effect of hard-water cations. A sodium alkyl-aryl sulfonate-type of detergent combined with the proper proportions of sodium carboxymethyl cellulose in as high as 15 g. water exhibits detergent properties superior to those of the synthetic detergent alone in distilled water. Methods having a relatively high order of precision for the evaluation of detergency have been presented in detail. By these methods two fundamental characteristics of detergency—carbon soil removal and whiteness retention—as applied to the laundering of cotton fabrics may be independently measured.

*Text. Research J. Dec. 1948* Authors

## Crystallinity of Polyamides

**A few experiments on the crystallinity of polyamides.** M. E. Bergmann, I. Fankuchen, and H. Mark. TEXTILE RESEARCH JOURNAL **18**, 1–8 (Jan. 1948).

This paper deals with experiments on nylon samples which were subjected to swelling in a dilute aqueous phenol solution and which, as a result, assumed a high degree of crystallinity. The degrees of crystallinity achieved, as well as any preferred orientation, were examined by means of x-ray diffraction diagrams, obtained with a 5-cm., flat-film camera, a microcamera, and a 50-cm., low-angle camera. The mechanical properties were tested by cold drawing under controlled conditions. The principal feature of this paper is that x-ray patterns were obtained at several intermediate stages of drawing and swelling. Commercial undrawn fibers have no preferred orientation and a fairly low degree of crystallinity. Cold drawing leads to a high degree of preferred orientation, but reduces the resolution of the x-ray pattern still further. Swelling an undrawn specimen produces a very high degree of crystallinity. Swelling a drawn specimen for 60 hrs. leads to a well-crystallized state, with the preferred orientation almost unchanged; swelling for several weeks destroys most of the orientation as well, and at the same time further increases crystallinity. The mechanical tests show an increase in Young's modulus from $0.9 \times 10^5$ to $4 \times 10^5$ lbs./sq. in. for the drawn over the untreated specimen, whereas swelling leads to an additional slight increase. In most cases the elastic limit is 1/20 to 1/15 of Young's modulus. However, in one specimen, which had been cold-drawn and relaxed (without swelling) several times, the elastic limit had not yet been reached after an elongation of 25%.

*Text. Research J. Dec. 1948* Authors

## Degradation of Tire Cords

**Degradation of rayon tire yarn at elevated temperatures.** R. C. Waller, K. C. Bass, and W. E. Roseveare. *Ind. Eng. Chem.* **40**, 138–43 (Jan. 1948).

The chemical and physical changes resulting from heating cords made of 4-ply, 1,100-den. viscose rayon at 150° or 170°C under different conditions of air, moisture, and vacuum were studied. Air and moisture caused the fastest rate of degradation. If sealed tubes were used, the presence of the products of degradation made the tests more severe than oven- or vacuum-ageing tests. The rate of oxygen consumption is nearly constant in the range of 0–2% moisture but increases rapidly above 2%. During the first 24 hrs. of ageing of dry yarn, the evolution of $CO_2$ is about $\frac{1}{2}$ the oxygen consumed, but when more than 2% moisture is present the $CO_2$ evolved is equivalent to the oxygen consumed. Heating reduces the moisture regain and increases the crystallinity of rayon; however, if either air or water vapor is excluded, the change is less pronounced. Yarn strength, cord strength, and fatigue are affected in different ways by heat-ageing. Cotton cords degrade much faster than rayon cords in the absence of air and moisture but in the presence of air and more than 2% moisture the order is reversed. Nylon cords age more slowly in a vacuum than rayon cords, but with an unlimited supply of air the ageing of nylon is more rapid. A. R. Macormac

*Text. Research J. Dec. 1948*

## Effect of Moisture

**Wetting of wool as a function of the duration of Fadeometer exposure.** Kermit S. La Fleur. TEXTILE RESEARCH JOURNAL **18**, 39–41 (Jan. 1948).

All the evidence obtained from the tests described corroborates the view that light exposure modifies the sulfur-containing groups of the wool fiber most, the chief one of which is the disulfide linkage of the cystine residue. There is a good correlation between the degree

was due to the formation of oxycellulose, owing to exposure to warm, humid conditions. It can be avoided by washing the materials immediately after printing, or by cooling and storing them under dry conditions.

*Text. Research J. Dec. 1948*

## Anti-Crease Treatments

**Textile materials. Anti-crease treatments.** M. C. Bayle. *Meded. Vezelinst. T.N.O.*, No. **78**, 1–51 (1946); *J. Text. Inst.* **38**, A419 (1947) (through *Chem. Abstr.* **42**, 5681*a* (Aug. 10, 1948)).

A survey of the literature in the field of anti-crease treatments for textile materials, particularly for rayon. In addition, results of experiments carried out in the Netherlands Government Fiber Research Institute are reported.

*Text. Research J. Dec. 1948*

## Wool Scouring

**New methods for the scouring of wool. I. Emulsions with triethanolamine and ethylene glycol.** V. V. Golosov. *Tekstil. Prom.* **6**, No. 9/10, 27–8 (1946) (through *Chem. Abstr.* **42**, 4757*b* (July 10, 1948)).

Owing to wartime unavailability of oleic acid and coriander oil, which were used in amounts varying from 20 to 30% in combination with 1–2% $Na_2CO_3$ and 79–68% $H_2O$ for the scouring of wool, substitutes were developed with little or none of these emulsifying agents. Mineral-oil emulsions consisting of solar or spindle oil (20–30%), $Na_2CO_3$ or 20% $NH_4OH$ solution (1–2%), and $H_2O$ (79–68%), emulsions containing 2–6% of an emulsifier such as Kontakt or Nekal in place of this alkali, and emulsions containing 15–25% of solar or spindle oil, 5–10% olein, 1–2% of $Na_2CO_3$ or of 20% $NH_4OH$, and 79–63% water were developed, containing no oleic acid. The present work involves development of emulsions containing 14–19% of oleic acid, 6% triethanolamine, and 80–75% of perfume oil or transformer oil, as well as emulsions containing ethylene glycol: 25% glycol, 3% oleic acid, 0.5% of 25% $NH_4OH$ or 12.5% glycol, 5% oleic acid, and 1% triethanolamine. These emulsions result in a partial saving of oleic acid and are odorless, oxidation-resistant, and very stable. **II. Emulsions without olein.** N. Polukarpov. *Ibid.* 28. In an attempt to produce wool-scouring emulsions containing no olein, the following formulations were obtained: 300 g. tall oil, 90 g. 36° Bé NaOH, 110 g. $H_2O$, 600 g. mineral or shale oil, this mixture then being diluted 3:1 with $H_2O$; 150 g. sulfonated tall oil, 70 g. 36° Bé. NaOH, 200 g. $H_2O$, 600 g. mineral or shale oil, this mixture then being diluted 3:1 with $H_2O$. Such emulsions are now in use in the factory where they were devised.

*Text. Research J. Dec. 1948*

## Differential Staining of Rayon

**Enhanced differentiation of skin and core in rayon fibers employing internal condensation resins.** G. Landells, S. H. Mhatre, and K. I. Narasimhan. *J. Text. Inst.* **39**, T148–52 (Apr. 1948).

It is demonstrated that treatments of the viscose filaments with urea formaldehyde and with melamine formaldehyde resins can increase the differential staining of skin and core. It is suggested that the results could be explained by the presence of the deposition of larger amounts of resin in the core. Photographs of staining effects with Congo Red and with Disulphine Blue VNS are given.

J. A. Woodruff

*Text. Research J. Dec. 1948*

# FIBERS: YARNS: FABRICS: MECHANICAL PROCESSES

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## Carding and Spinning

**Carding and spinning discussion.** Anon. *Text. Inds.* **112**, 102, 104, 106, 108, 111, 113 (May 1948).

A detailed account of discussions pertaining to carding, spinning, and twisting by southern mills with special attention to card-grinding cycles and nep counts.

A. L. Landau

*Text. Research J. Dec. 1948*

## New Dabbing Mechanism for the Noble Comb

**The dabbing mechanism in the Noble comb.** Howard Martin. *Text. Mercury and Argus* **118**, 93, 105 (Jan. 16, 1948).

To overcome expensive maintenance costs of the dabbing mechanism, a new dabbing technique has been developed. Differing noticeably from normal practice, the pins of the smaller circle, which is set at an incline according to circumstances, are arranged below those of the larger circle at the point of contact. As a result, the wool is inserted into the pins in 2 stages: first into the larger circle, and, later, into the smaller circle, thus eliminating the necessity of dabbing the two circles simultaneously and decreasing excessive wear on the heel of the brush. The angle at which the smaller circle is set permits and facilitates entry of the wool fringe into its pins. To prevent the wool from being raised out of the pins of the larger circle as the circles separate and to prevent the fringe from being dragged into the base of the pins, a holding-down knife and a supporting knife are needed. In special cases—for instance, burry wools—a short knife, a revolving circular brush, or a short extension to the dabbing brush may also be used. Also discussed are functions and operational data of the conventional dabbing mechanism and previous attempts to improve it.

*Text. Research J. Dec. 1948* L. A. Fiori

## Wool Drying

**Researches in drying wool.** A. G. Arend. *Text. J. Australia* **23**, 12 (Mar. 20, 1948).

Developments in wool-drying machines and an experimental apparatus setup for removing the surplus water from wool after scouring without using direct heat are given. Wet wool is exposed to the dehydrating influence of a surplus of calcium chloride, which for reconditioning

of modification and wettability. There is some evidence supporting the theory that absorbed water hydrates the polar groups of proteins and polyuronides (Mellon, Korn, and Hoover, *J. Am. Chem. Soc.* **69**, 827 (1947); Palmer, *J. Applied Phys.* **17**, 405 (1946)); thus the increase of polar groups in wool keratin caused by rupture of the cystine linkage might explain its increased wettability. Author

*Text. Research J. Dec. 1948*

### Water in Textiles

**On the distribution of water in cellulose and other materials.** Robert Simha and John W. Rowen. *J. Am. Chem. Soc.* **70**, 1663–5 (Mar. 1948).

Equations are given for the relationship between water and textile fibers based on the modern absorption theory and on a polymer-liquid mixture theory. Data for cellulose, silk, and wool are plotted in accordance with the 2 equations and the results suggest that the combination of water with these 3 textile materials within low vapor pressures regions can be described in terms of the adsorption theory. Under high vapor pressures conditions the system can be analyzed in terms of a theory of polymer-liquid mixtures. In the intermediate region a gradual transition occurs. A. R. Macormac

*Text. Research J. Dec. 1948*

## BLEACHING: DYEING: FINISHING

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### Applications of Dyes

**Some miscellaneous applications of dyes.** J. P. Gill. *J. Soc. Dyers and Colourists* **64**, 113–18 (June 1948).

Discussion of the type of dyes used and the method of use for polishes, carbon paper, crayons, candles, motor fuel, soap, food, anodized aluminum, plastics, inks, woodstains, medicine, photographs, cosmetics, natural button materials, sealing wax, match heads, sponges; also unusual wartime applications of dye materials. J. A. Woodruff

*Text. Research J. Dec. 1948*

### Dye Absorption by Jute

**Studies on the absorption of methylene blue by jute fiber.** P. B. Sarkar and H. Chatterjee. *J. Soc. Dyers and Colourists* **64**, 218–21 (June 1948).

The absorption of methylene blue by jute fiber, both raw and variously treated, has been measured under different conditions. The dye absorption depends largely on the pH of the dye bath, but is practically independent of time, temperature, and concentration. The maximum absorption agrees fairly well with the acid value of the fiber, both raw and treated. It is suggested that cationic exchange takes place between polyuronic acids of the fiber and methylene blue. The strong natural affinity of jute for basic dyes does not appear to be due to the presence of lignin, which has a comparatively low absorption value. A much deeper hue can be obtained with basic dyes if the fiber is given a mild preliminary treatment with dilute caustic soda at room temperature. Authors

*Text. Research J. Dec. 1948*

### High-Temperature Dyeing

**Dyeing studies at elevated temperatures. Use of temperatures between 200°F and 300°F.** G. L. Royer, C. L. Zimmerman, H. J. Walter, and R. D. Robinson. TEXTILE RESEARCH JOURNAL **18**, 598–614 (Oct. 1948).

An apparatus has been built for dyeing textiles in the temperature range of 200°F to 300°F, and fundamental dyeing data have been obtained using a wide variety of textile fibers. The high-temperature technique is particularly applicable in the dyeing of those fibers which require a long time for diffusion of the dye into the individual fibers when applied under normal dyeing conditions. The high-temperature technique increases the speed of dyeing to such an extent that dyeings which normally require hours can be done in a few seconds. Commerically acceptable dyeings have been made on wool and wool-cotton unions in less than 90 sec. at 270°F. In general, because of the short periods of contact at these high temperatures, the same extent of dyeing can be obtained without any greater change in the tensile characteristics than is obtained when an equivalent dyeing is carried out for a longer time at lower temperatures. The amount of thermal decomposition of a large number of dyes was determined, and a number which are suitable for high-temperature dyeing have been selected. A method for the application of dyes by padding and then developing at elevated temperatures has been worked out; this method, owing to the increased speed of dyeing, makes it practical to dye continuously at a rapid rate many fabrics which previously have not been dyed by a continuous process. Authors

*Text. Research J. Dec. 1948*

### Printing with Mordant Dyes

**The use of sodium dichromate in printing with mordant dyes.** D. S. Matveev and N. F. Mokhova. *Tekstil. Prom.* **6**, No. 9/10, 24–6 (1946) (through *Chem. Abstr.* **42**, 4756*d* (July 10, 1948)).

Printing and dyeing of cotton textiles can be carried out in a single-bath process wherein $Na_2Cr_2O_7$, glycerol, and a thickener (starch or tragacanth) are incorporated in an aqueous solution of the dye, the textile passing from this dye bath to a steaming chamber. Typical examples include a red-dye bath consisting of 20% alizarin paste 100, thickener 830, $Na_2Cr_2O_7$ 30 (1:1 in $H_2O$), and glycerol 40 g., and a yellow-dye bath consisting of chromocitronine 25, warm $H_2O$ 205, thickener 700, $Na_2Cr_2O_7$ 30 (1:1 in $H_2O$), and glycerol 40 g.

*Text. Research J. Dec. 1948*

### Tendering of Printed Cotton

**Discharge-printed cotton fabric. Tendering.** W. Taussig. *Ciba Rundschau* No. **71**, 2643–4 (1947); *J. Text. Inst.* **38**, A418 (1947) (through *Chem. Abstr.* **42**, 5677*b* (Aug. 10, 1948)).

Investigation of garments found damaged after discharge printing with hydrosulfite showed that this

most resistant materials of a series of plastic laminates tested by exposure to various combinations of moisture, heat, and ultraviolet light.
*Text. Research J. Dec. 1948*

## Trimmings

**Trimmings and their applications.** George Shackleton. *J. Text. Inst.* **39**, P107–13 (Mar. 1948).

Trimmings, whether knitted, braided, or in the form of decorative materials such as cords, fringes, tassels, etc., are divided into those made (1) on power looms, (2) on machines on which knitting forms the basic structure, (3) on braiding machines, and (4) by hand, and the construction and manufacturing techniques are described.
*Text. Research J. Dec. 1948* L. A. Fiori

## Kellog Loom

**Kellog loom has unique design features.** W. A. Newell. *Textile World* **98**, 118–21 (June 1948).

A report of the new Kellog loom together with photographs of integral motions. Special feature of the loom is the design of each motion mechanism as an individual unit. Precision is claimed to be of exceptional quality. A. L. Landau
*Text. Research J. Dec. 1948*

## Novel Loom

**New smallware loom.** A. Thompson. *Silk J. & Rayon World* **24**, 38–9 (June 1948).

Positive shedding, no overhead mechanism, novel system of warp tensioning, and horizontally sliding batten are a few of the features incorporated in this loom. Its operation is discussed. L. A. Fiori
*Text. Research J. Dec. 1948*

## Shuttle Boxes

The **shuttle box swell.** John H. Strong. *Text. Mercury and Argus* **118**, 672–4 (May 7, 1948).

A detailed review of types of swell arrangements in shuttle boxes and methods of setting them; 5 types of swell motions are illustrated.
*Text. Research J. Dec. 1948* L. A. Fiori

## Electrical Slasher Drives

**Electrical slasher drives.** Anon. *Am. Wool and Cotton Reptr.* **28**, 11–13, 52 (July 8, 1948).

Part 2 of a discussion of new electrical drives for slashers, illustrated with wiring diagrams. The function and operation of the drives are explained in detail. Advantages claimed are more uniform tension, higher yardage per beam, closer stretch control, and higher weaving efficiency. A. L. Landau
*Text. Research J. Dec. 1948*

## Electrically Driven, Moisture-Controlled Slasher

**The electrically driven, moisture-controlled slasher.** E. J. Eaddy. *Textile Bulletin* **74**, 71, 72, 74 (June 1948).

The component units of the electric drive and the controls as applied to the slasher are outlined and the advantages of the system are cited. A. L. Landau
*Text. Research J. Dec. 1948*

## New Uptwister

**A new double-deck uptwister.** Anon. *Text. Mercury and Argus* **118**, 923–4 (June 25, 1948).

It is claimed that this machine gives smooth vibrationless running at speeds up to 12,000 r.p.m. and uniform twist in the yarn up to 90 turns per in. and that it is ideally suited for the production of highly twisted continuous filament rayon, nylon, and silk yarns for hosiery and woven crepe fabrics. A general description of the twister's main features is given. L. A. Fiori
*Text. Research J. Dec. 1948*

## Automatic Hosiery Machines

**Automatic hosiery machines.** Anon. *Am. Wool and Cotton Reptr.* **28**, 9, 10, 51 (July 8, 1948).

The operation and adjustments of dial and cylinder needles on automatic hosiery machinery. A. L. Landau
*Text. Research J. Dec. 1948*

## Progress in Cotton Spinning Machinery

**Cotton type machinery.** Anon. *Textile Inds.* **112**, 213, 215, 217, 219, 221, 223 (July 1948).

Fifty yrs. of improved machinery design of cotton spinning machinery have resulted in the omission of two processes of picking and two or more processes of roving. Spinning frames have doubled in gage, and spin with long draft and at higher spindle speeds. The machinery of a 1910 and 1947 mill of equal capacity are compared.
*Text. Research J. Dec. 1948* A. L. Landau

## Woolen Machinery Development

**Woolen machinery development.** A. W. Reynolds. *Textile Inds.* **112**, 225, 227, 229, 231, 233 (July 1948).

A review of the progress in woolen machinery discloses that modern woolen pickers are larger and capable of higher production. A main change in the card has been the replacement of the tape condenser over the ring doffer for condensing the card web. Mule-spinning frames are being discarded in favor of ring-spinning frames.
*Text. Research J. Dec. 1948* A. L. Landau

## Improvements in Woolen Machinery

**Research methods in weaving machinery.** F. M. Fitzgerald. *Rayon Text. Mo.* **29**, 55–6 (May 1948); 64–5 (June 1948).

Weaving research is directed generally into 4 channels: improvement of the present type of loom, reduction of cost of warp and filling handling, design of looms to weave without conventional shuttle and bobbin, and machinery for production of nonwoven fabrics. Each phase is described. L. A. Fiori
*Text. Research J. Dec. 1948*

## Worsted Machinery Development

**Worsted machinery development.** H. V. Farnsworth. *Textile Inds.* **112**, 235, 237–38C (July 1948).

is then passed along a miniature conveyer belt through a heated chamber, from which the salt is discharged completely dried and ready for reuse. Although this method prevented injury from overheating, mechanical application of the dehydrating agent was still slow compared with machine methods now in use. L. A. Fiori

*Text. Research J. Dec. 1948*

### Opener Drive

**New drive for vertical opener.** Anon. *Saco-Lowell Bull.* **20**, 6 (Feb. 1948).

A new and simplified driving arrangement for the vertical opener is illustrated and described.

*Text. Research J. Dec. 1948* L. A. Fiori

### Horizontal Openers

**Horizontal openers.** R. Z. Walker. *Textile Bulletin* **74**, 68–71 (June 1948).

The use, adjustments, and operating speeds of the horizontal opener for cotton mills are reviewed.

*Text. Research J. Dec. 1948*

### Opening and Picking

**The modern blowing room.** S. Tarbuck. *Text. Mercury and Argus* **118**, 595, 597, 599, 601 (Apr. 23, 1948); 640–1 (Apr. 30, 1948).

Modern and old methods in the opening and picking room, and settings, speeds, and recommended practices for beaters used with the different types, grades, and staples of cotton are discussed. L. A. Fiori

*Text. Research J. Dec. 1948*

### Synthetic Fiber Pickers

**Improved synthetic fiber picking.** Anon. *Am. Wool and Cotton Reptr.* **18**, 11, 12, 20 (Apr. 29, 1948).

A discussion of the picker and the mechanical improvements and types of machines suitable for the picking of synthetic staple fibers. The problems of blending evenly are reviewed. A. L. Landau

*Text. Research J. Dec. 1948*

### Spinning on American System

**Spinning cotton, rayon and wool on the "American" system.** R. J. McConnell. *Can. Text. J.* **65**, 52–4 (June 25, 1948).

Discussion of the American system of producing worsted yarns.

*Text. Research J. Dec. 1948*

### Ring Spinning of Woolen Yarns

**Woolen yarns: Some advantages of ring spinning.** Anon. *Fibres* **9**, 217–8 (June 1948).

Comparisons between old type frames and frames of today show that great advances have been made. Features of modern woolen ring spinning frames are summarized. Details of a new frame of revolutionary design are given.

*Text. Research J. Dec. 1948* L. A. Fiori

### Worsted Spinning

**Flyer spinning of worsted yarns.** Anon. *Fibres* **9**, 229–31 (June 1948).

A review of the features incorporated in the new type of flyer spinning frames for worsted yarns.

*Text. Research J. Dec. 1948*

### Machine Twisting

**Warp twisting-in machine technique.** H. E. Wenrich. *Rayon Text. Mo.* **29**, 70–2 (Apr. 1948).

Machine twisting, even in the smaller weave sheds having fewer than 50 looms, improves efficiency by increasing output and producing a better twist or knot. It requires less floor space and, most important, lowers cost to a fraction of that of hand twisting. The technique of harness setup, practices when twisting-in colored yarn, and other suggestions for time-saving patterns are given. These machines can be used on most synthetic weaves as well as on silks, spun yarns, and other fine numbers. One of the most important phases of twisting-in rayon and silk warps is preventing yarns from slackening during the pull-through. L. A. Fiori

*Text. Research J. Dec. 1948*

### Crepe Warping Techniques

**Crepe warping techniques are applicable to Bemberg.** J. Gassman. *Textile World* **5**, 113, 190 (May 1948).

The method of warping Bemberg crepe on the cotton low-speed warper is explained. A. L. Landau

*Text. Research J. Dec. 1948*

### Oscillograph Application

**Loom study by means of the cathode-ray oscillograph.** N. H. Chamberlain and D. C. Snowden. *J. Text. Inst.* **39**, T23–43 (Feb. 1948).

A method is described in which the variations occurring in individual warp-thread tension during the weaving cycle are recorded photographically from traces obtained on the screen of a cathode-ray oscillograph. Representative traces are reproduced and their significance is discussed. Analysis indicates that the behavior of a loom when running at weaving speed is often different from that which would be anticipated from a study of the mechanisms at rest or in slow motion. The occurrence of a double beat-up in certain cases and the inertia effects in the warp control mechanism are examples of this fact. The oscillograph itself is described in some detail but particular attention is focused on the auxillary apparatus required to effect the voltage translation, which itself has certain wider and more general applications.

*Text. Research J. Dec. 1948* L. A. Fiori

## MISCELLANEOUS

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### Effect of Service Conditions on Plastics

**Effect of simulated service conditions on plastics.** W. A. Crouse, D. C. Caudill, and F. W. Reinhart. *Natl. Advisory Comm. Aeronaut., Tech. Note*, No. 1240, 21 pp. (1947) (through *Chem. Abstr.* **42**, 2469*d* (Apr. 10, 1948)).

Asbestos-fabric phenolic laminate and glass-fabric unsaturated polyester laminate were found to be the

Improvements in worsted machinery over the last 50 yrs. have made possible higher production and closer control during opening, washing, and drying. Intersecting gill boxes are claimed to be one of the most important advancements in recent years. Cap spinning and mule spinning have been replaced by ring spinning in most mills.

*Text. Research J. Dec. 1948* A. L. Landau

## Swiss Machinery

**Modern Swiss textile machinery.** Anon. *Textile Recorder* **66**, 47–51 (Aug. 1948).

An illustrated review of outstanding Swiss machinery developments.

*Text. Research J. Dec. 1948*

## Textile Waste Treatment

**The industrial waste problem. IV. Brass and copper, electroplating, and textile wastes.** William S. Wise. *Sewage Works J.* **20**, 96–102 (1948); *cf. C.A.* **41**, 3732*d* (through *Chem. Abstr.* **42**, 3882*g* (May 20, 1948)).

Textile wastes are treated chemically with alum, $FeSO_4$, $Fe_2(SO_4)_3$, CaO, and $CaCl_2$ to reduce the O consumed 60–80% and suspended solids 80–98%.

*Text. Research J. Dec. 1948*

## Humidification and Air Conditioning

**Humidification and air conditioning.** R. S. Parks. *Textile Inds.* **112**, 158–62 (July 1948).

A discussion of the progress in textile mills of humidification and air-conditioning equipment, ranging from the vapor pots and floor sprinkling of 50 yrs. ago to the precision equipment used today.

A. L. Landau

*Text. Research J. Dec. 1948*

## Humidification Cuts Picker-Room Fires

**Humidification cuts picker-room fires.** R. G. Shepherd. *Textile World* **98**, 110–11 (Aug. 1948).

Tests have shown that the rate of spread of fire on opened cotton fibers is influenced by the moisture content and density of the fibers, the angle of inclination of the stock, and the surrounding air movement. Cotton with a moisture regain over 6.5% to 7% is approximately 35% less susceptible to ignition than drier stock. A. L. Landau

*Text. Research J. Dec. 1948*

## Mill Construction and Layout

**Mill construction and layout.** A. D. Asbury. *Textile Inds.* **112**, 151–7 (July 1948).

A report of the changes in design and machinery layout of the cotton mill which have taken place in the last 50 yrs. The developments making such changes possible are explained. A. L. Landau

*Text. Research J. Dec. 1948*

## Calculation of Repair Costs

**A common denominator for repair costs.** David E. Pierce. *Chem. Eng. Progress* **44**, No. 3, *Trans. Am. Inst. Chem. Engrs.* 249–52 (1948) (through *Chem. Abstr.* **42**, 2481*a* (Apr. 20, 1948)).

Study of data from a cross section of the chemical industry indicates that the amount of electrical energy consumed in a plant is a good measure of the activity of that plant. It is, therefore, possible to use 1,000 kw.-hrs. as a unit of activity and to refer the various components of plant cost to kw.-hrs. as a common denominator. By this means, a formula has been developed for the cost of repairs which permits comparison of different plants and of various departments in those plants for any desired period of time.

*Text. Research J. Dec. 1948*

## Fiber Consumption in United States

**Trends in the consumption of fibers in the United States, 1892–1946.** Robert B. Evans and Barkley Meadows. New Orleans, La., Southern Regional Research Laboratory, U.S. Dept. of Agriculture, June, 1948. 108 pages. Free.

Basic statistics on consumption of textile and cordage fibers in the United States are presented in 60 tables with accompanying charts. Data are presented on mill consumption of raw fibers, consumption of fibers by ultimate consumers, quantities of fibers used per capita, trends in domestic and foreign origin of fibers used, and on exports and imports of textile products. Data for 1947 are given in an addendum. R. B. Evans

*Text. Research J. Dec. 1948*

## Buyer Preferences

**Women's preferences among selected textile products.** Bureau of Agricultural Economics. Miscellaneous publication no. 641, U.S. Dept. of Agriculture. Washington, U.S. Government Printing Office, 1947. 124 pages. 25 cents.

Results are given of a survey of 1,782 women selected statistically to give an accurate sampling of the 45,000,000 women in the United States. Percentages of women who do and do not buy 16 items of ready-made clothing and household articles are given. A majority of women preferred cotton for house dresses, nightgowns, pajamas, anklets, aprons, tablecloths, bedspreads, and lightweight curtains; but they preferred nylon for full-length hosiery, rayon for blouses and summer slips, and rayon or wool for winter street dresses. Good laundering qualities, durability, and nice appearance were most often cited as important characteristics in house dresses, summer street dresses, blouses, and curtains. Main points of dislike for ready-made cotton clothing were that it was not colorfast, was not good-looking, and was thin and sleazy. Main disadvantages of rayon clothing were that it frays and pulls at seams, melts and sticks to iron, is not durable, and shrinks and stretches. Findings with respect to each item are discussed. R. B. Evans

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